m2k, 4/21/94

CHAPTER 2

ORIGINS OF MUSICAL INSTRUMENTS

It is curious that more is known about the rather vague quasi–mystical, quasi–aesthetic, quasi–mathematical course of music theory than about the definite facts concerning how the physical instruments were developed. The history of music theory is well recorded, from Pythagorus (about 580 B.C.) to the present.

From India there is the *Nātya–Shāstra*, perhaps as old as 200 B. C., in which instruments were classified in four categories: the stringed, wind, membranous percussion, and metal percussion. Evidently, by then there must have been already a long period of development. This continues in the *Sangita Makarandah* of the 8th or 9th Century, the *Sangita–Ratnākare* of the 13'th Century, and the *Rāga–Vibodha* and *Chaturdandi Prakāshika* of the 17'th Century, down to the *Hindusthani Sangita Paddhati* of V. N. Bhatkande, in the 20'th Century.

Arab theoreticians include Al–Kindi ($\simeq$ 873), Al–Farabi (950), Avicenna (1037), and Safe al–Din (13th Century). They discourse on mystical properties, then proceed to more mundane matters of calculation of intervals, definition of modes, rhythm, principles of composition, and properties of instruments that composers need to know.

Early European works after Pythagorus are rare but not entirely unknown; for example the *De Musica* of St. Augustine (late 4'th Century), and another *De Musica* by Aurelian (c. 850). But starting in the 16'th Century, we have a veritable flood of European works on music theory: Tartaglia (1543), Gioseffo Zarlino (1558, 1588), G. Benedetti (1563, 1585), Vincenzo Galilei [father of Galileo], (1589), Simon Stevin (1605), Father Marin Mersenne (1636), Jean Philippe Rameau (1722 *et. seq.*).

In contrast, the process by which one evolved the actual design and mechanical construction of the instruments was often not recorded. In early times this knowledge was handed down verbally from master craftsman to apprentice – no doubt, often secretively – and is now lost. We shall be concerned mostly with the violin, about which quite a bit is known, and the piano, for which we know in detail just how its present form was developed. But before turning to them, let us survey a little of what is known about other instruments.

The Migration Theory

Historical scholars tell us that lutes, fiddles, flutes, oboes, trumpets and drums did not originate in Europe, but were brought there from the Orient and the Near East, mostly before medieval times. At first hearing, this seems so implausible – or at least so unflattering to our Western ego – that one will demand to know the specific evidence for it. Quite independently of the blow to our pride, what the migration theory makes so hard to explain is this: if such instruments were already well developed and used for Centuries in the East before coming to Europe, why did oriental music never develop any sense of tonality and harmony?

Without going into a lengthy historical analysis, we can indicate the general nature of the evidence for the migration theory (for many more details, see Schaeffner, 1968). In the first place, the works on music theory just cited show a preponderance of oriental activity before the 16'th Century. The earlier European works are concerned mostly with vocal Church music. Secondly, evidence still in the East and near East (stone statues, temple carvings, tombs) shows many familiar looking instruments, already in ancient times.

Thirdly, the main routes by which such migration could have occurred seem to be; the movement of Arabs into Spain starting in the year 711,[†] the returning Crusaders, the Marco Polo type explorers and traders of the 13'th and 14'th Centuries, and the invasions of the Ottoman Turks into Anatolia and then into central Europe in the 15'th to 17'th Centuries. Now in each case we have historical proof that musical instruments *were* carried westward in these migrations.

The evidence for this is particularly complete and detailed in the case of Spain. The photographer Bradley Smith has taken beautiful color photographs of paintings and parchments found in various museums, churches, and public buildings all over Spain, that convey historical information about the period in which they were painted, and presented them in a magnificent volume (Smith, 1966). They depict many musical instruments, in greater detail than most of the Egyptian illustrations. For example, two 13'th Century illustrated parchments show (p. 60) an elaborate seven–string lute of the classical shape, being played; and (p. 63) an equally elaborate harp, of entirely different basic design than the Egyptian ones. On pp. 84–85, we see citterns (which appear to be intermediate forms in the evolution of the lute into the modern Spanish guitar), flutes, and – surprisingly – bagpipes. Of course, early instruments had many and various names different from our present ones; but their basic kinship is evident from illustrations and surviving specimens. For example, the Arabian stringed instrument called *Al–Shaqira* is found in Spain in the 13'th Century, and it had migrated on to England by the 14'th Century.[‡]

Finally, nobody has been able to find any evidence for such well–developed instruments being in Europe before those times (there have always been primitive peasant inventions known only locally). The sudden appearance of many European works on music theory in the 16'th Century seems to indicate that instruments deserving of serious study suddenly appeared in Europe shortly before then. So the evidence for the migration theory is rather convincing, and it seems that we must look elsewhere for an explanation of why the elements of tonality and harmony should be peculiar to Europe. Here we can only conjecture.

[†] The Moslems remained in Spain for nearly eight Centuries, during which they acquired, at one time or another, control over most portions of the Iberian peninsula. Thus not only some of their culture, but also some of their racial character, was absorbed by the native Spanish population, and is by now diffused throughout most of it. This is the reason why Spain still presents, to a traveler, a quite different appearance and culture than does any other European country.

[‡] For much of this information we are indebted to Alfonso X (often called *El Sabio*), who ruled in Toledo from 1252–1284 and commissioned many paintings and translations of Arabic works into Latin. In particular, his *Cantigas* contains, according to Smith (1966), illustrations of over 50 types of musical instruments used in 13–th Century Spain and examples of the music. We understand that this is now in the magnificent library of *El Escorial*, the 16'th Century Royal Palace of Philip II near Madrid. How we would like to have a photographic reproduction of it!

There is a hint of a rudimentary tonality in the ancient Greek modes, and although 'consonant' and 'dissonant' intervals were recognized, they seem nearly arbitrary. It seems a plausible conjecture that to develop a sense of harmony in the modern sense required keyboard instruments, so that one person could play easily any combination of notes. Only after some rudimentary principles of harmony were recognized could one perceive the fundamental status of the major scale, which distinguishes it from the other modes, leading to tonality in the modern sense of the word.[†] Since keyboard instruments appear to be European products, this conjecture has at least some self–consistency, even if we are unable to cite a definitive proof of it. Perhaps others can suggest better conjectures.

How are Musical Instruments Developed?

Every musical instrument, needless to say, requires a long period of development – usually trial–and–error experimentation by generations of craftsmen – before arriving at its final perfected form. An instrument such as the clarinet or French horn, whose development took place in Europe in the 18'th or 19'th Centuries, has left a trail of historical record readily available. But even the harpsichord and violin, although European products, are too old to meet this condition.

For the many instruments that were imported from the East long ago, the details of this development are completely lost in unrecorded history, and only the evidence of archaeology can shed any light on them. Elaborate harps are found, already highly developed, in tombs in Asia minor dating back to 3500 B.C. Fancy harps, lyres, and instruments resembling guitars and oboes are depicted in numerous carvings on the walls of Egyptian tombs of about 2600 – 1000 B.C. An authentic specimen of an Egyptian harp of about 1400 B.C. may be examined in the Metropolitan Museum of Art in New York, well enough preserved so that one can see exactly how it worked. It is surprising to see the sounding board already there, built into the thick bottom. Evidently, practical knowledge of the properties of strings and the facts of acoustics did not begin with Pythagorus. Also, drums essentially identical with modern bongo drums were found in Egyptian tombs of about 1000 B. C.

Brasses. For wind instruments the early history is likewise lost. The straight trumpet was known in ancient times; four specimens were found in the tomb of Tutankhamen (about 1350 B. C.), whose photographs may be seen in Manniche (1991).[‡] A folded version was developed, in the 14'th or 15'th Century, to make it easier to carry. The slide trombone (Italian for "big trumpet") evolved out of the folded trumpet in the 15'th Century, before the invention of valves, as the easiest way to play a full scale. Sixteenth Century engravings

[†] Of course, it is easy to pluck two lute strings simultaneously, thus producing what to our ears is perceived as a simple harmony. The Elizabethan lute songs already demonstrate this, and we readily interpret them as parts of our modern tonic, dominant, and subdominant chords. But that is only because of our long familiarity with harmonic effects; it seems likely that to Elizabethan ears the sound of two simultaneous notes was perceived in contrapuntal rather than harmonic terms.

[‡] The greatest collection of ancient Egyptian instruments is, of course, in the Cairo museum; however, the Metropolitan museum in New York and the British museum in London also have interesting collections, accessible to more people.

show folded trumpets very much like modern ones except that they have no valves; and trombones that look identical with our modern instruments except for a narrower bell.

The major advance in brasses was the invention of valves in about 1815. These changed the length of tube, allowing the full chromatic scale to be played. The patent, by Heinrich Stölzel and Friedrich Bluhmel, is dated 1818 and pertains to improvements in horns; but once seen the idea spread rapidly to other brasses. By 1825 the modern cornet existed, and by 1835 the modern tuba had been invented (in Germany, of course – where else?)

The French horn was originally an 18'th Century hunting horn, without valves, and coiled up in circular form so that it could be carried about on the shoulder by sticking one's arm through it, and played by a hunter on horseback, the bell turned up rather than down as now. But the valves then filled the central space so it could no longer be held that way. It turned out to be notoriously difficult to play clear, burble–free tones on the French horn. We are used to hearing a French horn, not playing a clear melody, but *trying* to play a melody, with a little uncertainty at the start of each note as to whether we shall actually manage to get it. The trouble is that the total length of the coiled horn is very large for the pitch of the notes being played, so one has the same problem as a bugler trying to play very high notes. The slightest change in lip tension can cause it to jump from one note to another; it is like trying to play a long garden hose.[⋆]

Woodwinds. The flute has been known from antiquity; carvings on ancient temples in India show them just the same size, and held in the same way, as our modern instruments. Manniche (1991) gives several reproductions of drawings in Egyptian tombs of roughly 2600 – 1000 B. C., showing some kind of tubular instrument with the end apparently in the mouth. She classifies them confidently as clarinets, oboes, and end–blown flutes; but we are unable to see anything in the drawings that could justify such a distinction. Even given a surviving specimen, what is the distinction between an end–blown flute, and a clarinet missing its mouthpiece? Both are just tubes with holes in them.

What is the difference between a clarinet and an oboe? In ancient instruments, this is arbitrary, and more a matter of semantics than of fact. If the distinction is held to lie in the single or double reed, then one could convert an oboe into a clarinet and vice versa, merely by changing the mouthpiece. Manniche (1991) uses this classification in one place, and in another – in seeming contradiction – makes the distinction in terms of the bore diameter, an instrument with a hole less than 1 cm in diameter being called an oboe – with no mention of the shape of the bore.

But neither of these classifications recognizes the real distinction between our modern oboe and clarinet. This distinction is in their entirely different tone; and this is caused by the clarinet having a cylindrical bore (uniform diameter from one end to the other), the oboe a conical one, tapering from a small hole at the mouth end to a large one at the bell.[†]

[⋆] Indeed, as the virtuoso French hornist Dennis Brain has demonstrated, one who has mastered that instrument can play a garden hose just as well.

[†] As a result, their body resonances are entirely different; the oboe has all harmonics, the natural frequency ratios 1:2:3 and so on, while clarinet has only the odd–numbered ones, frequency ratios 1:3:5 and so on. This accounts for the distinctive "hollow" tone of the clarinet in the low register. This same hollow tone is produced by plucking a string at its exact center, which makes all even–

It is easy to prove that this difference in tone has nothing to do with a single or double reed; clarinet–type single reed mouthpieces that fit onto an oboe body can be bought commercially, and the resulting instrument still has the tone and musical function of an oboe, not a clarinet. If one is used to playing a clarinet, but in an emergency situation is obliged to play an oboe instead (as once happened to the writer in a college orchestra when the regular oboist was taken sick and at the conductor's request I underwent a crash program to learn oboe fingering in one day), one can play the unfamiliar instrument with better control by keeping the familiar kind of mouthpiece. Conversely, by drilling a small hole in a cork you can fit an oboe double–reed mouthpiece onto a clarinet body. The resulting instrument is still functionally an authentic clarinet, not an oboe.

It seems to us incongruous and illogical to classify an ancient instrument as oboe or clarinet according to a criterion that would not be valid for our modern oboe and clarinet. More generally, we think it is a mistake to try to classify any ancient instruments in exact modern terms; it is enough to say that they were obvious forerunners of several modern instruments, sharing some of their features.‡

The Upper Register. Of course, these ancient instruments had no keys; only holes and generally only six of them. Then the musician could play seven distinct notes, in a mode that is built into (*i.e.*, determined by the construction of) the instrument. Now the ancient Egyptians used a peculiar arrangement, an oboe–like or clarinet–like instrument in which two tubes proceed either from a single mouthpiece, or from two mouthpieces held simultaneously in the mouth. But the very numerous tomb drawings give sufficient detail – all in agreement – so that we can understand their function. Both tubes had holes, covered by the fingertips; but each hand enclosed both tubes with the right hand generally above the left. So the upper notes were played by the right hand on the left tube, the lower notes with the left hand on the right tube. In other words, the appearance of a two–tube instrument simply tells us that the principle of the upper register had not yet been discovered. In fact, it was not discovered for at least a thousand years thereafter; numerous wall paintings found in Pompeii (Schefold, 1956) and in Etruscan tombs in Tarquinia (Pallottino, 1956) show the same two–tube arrangement, in much better detail than do the Egyptian sketches.

Eventually it was found – almost surely by a serendipitous accident like a cracked tube – that opening a very carefully placed small hole near the mouthpiece allows a single tube to play at a higher pitch called the upper register.⋆ On the clarinet, with its uniform

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numbered harmonics disappear. As noted below, this also accounts for the different effects of the register key in a clarinet and oboe.

‡ In exactly the same sense, the pterodactyl was a forerunner – perhaps an ancestor – of modern birds, sharing some of their features; yet it would be absurd to try to classify the pterodactyl as belonging to any particular modern bird species.

⋆ As a scientist would explain it today, this hole must be placed at or very near a "node", or point of minimum sound pressure, for the upper register vibration mode; then opening the hole drains sound energy from the lower mode but not the upper, causing the instrument to speak out in the upper mode. All this is explained in detail by Benade (1990). Exactly the same physical principle is used today in the multimode laser, in which the emitted light can be made to jump from one color to another by varying the loss in the different modes.

bore, opening the register hole causes the frequency to rise by a factor of 3, or the pitch to jump a twelfth, while with the conical bore of the oboe the natural modes are different, as noted above, which causes the jump to be an octave.

With discovery of the upper register, in principle up to seven more notes become available with six holes. To go beyond that and play intermediate notes (a pseudo–chromatic scale) would be possible but quite complicated, because as in the toy ocarina, this would require different combinations of open and closed holes, so generally more than one finger would have to be moved for each new note in the scale. It would require a real virtuoso to execute a chromatic scale smoothly.

Although they must exist, we have never seen an analysis of the hole positions on a surviving ancient instrument, to deduce the scale, or mode, that it used. It is possible that no two instruments were alike in this respect, in which case each instrument would play its own distinct mode. If so, this would help to explain why elements of harmony do not seem to have developed; each performer would be necessarily a melodic soloist unto himself. It is true that many drawings show several musicians in a group with several different instruments; but of course the drawings do not tell us whether they played simultaneously or in sequence.

Not only drums and trumpets, but also oboes which now seem to have upper registers, were used by the Turks in the 17'th Century, played by mounted bands accompanying their armies, who invaded Europe marching to music. In spite of our horrified disapproval of all the other antics of the Turks of that time, we did admire their music; it inspired Mozart's "Turkish March" rondo which young piano students must learn, and our modern military bands have evolved from them. For evolution of the modern keyed oboe from the ancient form, see Philip Bate (1956).

An instrument like our modern clarinet appeared in the 18'th Century (for details see Baines, 1963; Rendall, 1971), and Mozart was also the first composer to appreciate its possibilities (although it was Brahms who brought them out fully). Note the Mozart Trio in E$\flat$, K. 498 of 1786, for the remarkable combination of piano, viola, and clarinet; the writer has played the piano part of it many times, but does not understand how it was possible to play the clarinet part on any clarinet that existed in 1786.

The advance from the ancient forms did not start until the late 18'th Century, when the idea of adding metal keys to do what human fingers could not reach started a gradual, but haphazard evolution. To cite only a few examples of the dozens that are known, Kusder of London was producing a 5 key bassoon in 1780. Likewise, in London Potter was making a 6 key flute in 1795, and Clementi & Nicholson an 8 key flute in 1820. G. Astor of London was producing a 5 key clarinet in 1785, which advanced to a 6 key instrument by Astor & Horwood in 1810. Then in the period 1810 – 1840 many kinds of different 10 to 13 key clarinet systems were made. Similar developments, different in details, proceeded simultaneously in France and Germany, so by 1835 there was a situation of total chaos: dozens of different key systems, each of which solved some particular problem but none of which was really satisfactory in all musical situations.

To bring order out of this required an exceptional individual. Theobald Böhm was a German trained in the family goldsmith business, who became also a virtuoso flautist, performing on concert tours. It required this unique combination of talents to understand the totality of what was needed musically; and at the same time to know how to make it in the metal. In 1832 he invented the key ring and a system of keys that accomplished a chromatic scale of a few octaves for the flute. He also wrote a book, recently translated and republished, explaining it. The modern Böhm flute reached essentially its present state of development by 1847; its key arrangement makes it easy to play passages that were difficult or impossible on earlier instruments. For details, see Philip Bate (1969), Nancy Toff (1979), Theobald Böhm (1992).

In about 1840, C. Sax and E. Albert of Brussels devised a key system for the clarinet which was standard for many years as the "Albert system" clarinet. In 1843 the clarinetist H. Klose and the instrument maker Auguste Buffet, in Paris, patented a still better design following the principles of Böhm for the flute, which became known as the "Böhm clarinet". The two systems were in competition for many years; when the writer was a child making unpleasant sounds on them, Albert clarinets were still to be found in school orchestra collections, and so was advertising to indoctrinate us into the advantages of the Böhm, giving examples of passages that are impossible to execute smoothly on the Albert, but easy on the Böhm. Today, other post–Böhm key systems are being made.

In this work we do not go deeply into the properties of wind instruments, because it is unnecessary; the greatest modern authority on wind instruments, Arthur Benade (1990) has written a fine and almost overwhelmingly complete exposition with far more details than we could give here. This is the first source to consult for properties of wind instruments; no other author has a fraction of his understanding of the physical principles or his experience with fine–tuning these instruments for optimum tone and responsiveness.

The Lute and the Minstrel's Fiddle. These instruments became, so to speak, the parents of the violin, which shares some features of both. The lute was imported from the East in very early times so we do not know its exact antiquity; primitive versions were present throughout the available historical record.

Ancient Egyptian tombs also have numerous drawings depicting familiar looking instruments, which Manniche (1991) again classifies confidently as lutes, mandolins, and guitars although we are unable to see anything in the drawings to justify such distinctions and relatively few specimens have survived. But we have hundreds – perhaps thousands – of tomb drawings depicting them in use. Invariably they are plucked; the principle of the bowed string was evidently not yet discovered although the archer's bow was well known in ancient Egypt. Once again, we think it is a mistake to try to force modern classifications, which did not exist in ancient times, onto ancient instruments; it is enough to say that they are obvious forerunners of several modern instruments.

In any event, later historical records show that in the Near East the lute was highly developed, and was the basis of Islamic music of the period of the Umayyad caliphate (661–750), where it reached its "classical" shape, and it was imported into Europe some time afterward; we have already noted its appearance in Spain in the 13'th Century. By the 16'th Century it had become a very popular instrument in Elizabethan England.

The principle of the bowed string does not seem to have originated in the East; it is conceivably a simpler and more satisfactory version of the hurdy–gurdy principle described below. A bow would be easier to make, more reliable, and under better control by the player. In any event, the minstrel's fiddle (or fiddel) was perhaps the most popular of all instruments in medieval Europe. Numerous old illustrations (see, for example, the Larousse Encyclopedia of Music, 1974) show it having a roughly oblong box about 18 inches long, 8 inches wide with rounded corners. The heavy box was hollowed out from a single block of wood, then the thin top sound board was attached. The bridge was placed in the center of the sound board and it usually carried four strings, which were bowed across the handle at the point where it joins the box. The bow was literally a true "bow", with a circular arc like an archer's bow.†

But because of the distance from the end of the box to the bowing point, this could not be played as a violin is today, held securely between the player's chin and left shoulder. The bowing point would be too far away for human arms to reach, if the bow is to remain perpendicular to the strings. In fourteenth Century illustrations showing it in the act of being played, it is held either vertically by a seated player, clamped between the knees like a cello, or if the player must stand and move about it is held awkwardly and precariously in a horizontal position across the shoulders; the left hand is on the strings, the bow is in the right hand moving vertically to the left of the left shoulder; but the box is so long that it extends a few inches beyond the right shoulder. One cannot tell what is supporting it; perhaps there was a hook on the back that rested on the right shoulder. It was just not a practical way to manage things.

One should be warned not to take these old artist's illustrations too literally; depictions of musical instruments being played are often inaccurate because the artist did not observe the musicians carefully in actual playing. Looking only at a musician holding a fixed pose, one would not understand what was important. Old illustrations often show instruments being held in ways that would make it impossible to play them; violins being bowed across the broad part of the instrument, fiddles held so the bow makes a 45 degree angle with the string, *etc.*

Early Instrumental Music

Of course the human voice, being the most available of all sound producers, would be prominent in the music of early times; but still we may be surprised at the degree of that prominence and how little purely instrumental music existed in those times, even though a wide variety of instruments was available for it. Thomas Morley (1557?–1602) introduced his *Fantasia* for five recorders with the comment: "*This is the most Principall and Chiefest Musick which is made without a ditty.*"

In early music, even where instruments are used prominently, there is what seems to us a curious reluctance to make use of their full capabilities. In the Elizabethan lute songs, where today we would expect the lutenist to break into a virtuoso passage, there is instead a peculiar halting quality, as if the composer or the performer were not quite sure what to do next.

On the other hand, music of the Elizabethan period already shows that full awareness of the capabilities of the human voice, that comes with long experience. An elaborate ballad with really creative passages for the voice, named "*My Lord Willoughby's Walkin'*

† Medieval fiddles can still be bought today; see the "Lark in the Morning" catalog in our bibliography.

Home" sings of the exploits of an English General against the Spanish Army – not a very promising topic for a popular song. But its musical quality was such that it spread all over Europe and became, so to speak, one of the Top Ten Hits of the 17'th Century.

Presumably, the explanation is that even after an instrument has reached a high state of technical perfection, it may require generations to become fully aware of its musical capabilities. Late in life, Johannes Brahms testified to his own slowness to appreciate the expressive capabilities of the cello – on hearing the Dvorak cello concerto he exclaimed: "Why on earth didn't I know that one could write a cello concerto like this? If I had known, I would have written one long ago." This from the man who had already written the double concerto and the cello parts for four symphonies and about two dozen chamber music works.‡

The Violin

It appears that the European lute and fiddle makers gradually evolved their instruments into the modern violin. But what accounts for the peculiar narrow–waisted shape of the violin, which neither the lute nor the fiddle have? A writer of pamphlets on early instruments for the Metropolitan Museum of Art supposed it to be only aesthetic: "··· they were given beautiful shapes by instrument makers who felt beautiful sounds should come from beautiful instruments." Let us point out, then, that the choice of that shape had nothing to do with aesthetics; it was forced on the makers by the need to make a very practical compromise.

The main necessity was to get the bowing point closer to the end of the box, so human arms could reach it. But on the one hand, to get a good volume of sound a large, broad box was required for the same reason that a piano needs a large sounding–board. On the other hand, to move the bow from one string to another, it was necessary to tilt the bow without colliding with the box.

One solution was to move the bridge and bow up nearly to the end of the box opposite to the handle, but separate the strings so widely at that point that a very small tilt would move the bow from one string to the next. Indeed, some early illustrations show this solution, a modified minstrel's fiddle held like a violin, with the bow passing across the broadest part of the instrument, where it could hardly be tilted at all. But the smaller the tilt from one string to the next, the harder it was to play on the right string reliably. To ensure reliability a strongly curved bridge was needed; but then a narrow box was required, to permit the bow to be tilted through large angles.

In the end, the reliability consideration prevailed, and the successful solution was to make the box narrow in the region where the bow moves across it, broad elsewhere. Then one can put the bowing point wherever one wishes; and the place finally chosen as most comfortable results in the bow passing about five inches from the tip of the player's nose. In the modern violin, the bow can be tilted nearly twenty degrees from one double stop position to the next; thus the performer has a wide margin of safety against inadvertently bowing the wrong string.

‡ The Brahms F major cello sonata is a work so busy that the cello is never allowed to sustain a note long enough to bring out any expressive quality.

Presumably, the fact that it was possible to adopt this narrow–waisted box shape without disaster was discovered in many cautious small steps, by anonymous craftsmen in the early 16'th Century. Michael Praetorius (1619) gives illustrations of instruments with a transitional shape intermediate between fiddle and violin, a shallow waist beginning to form in approximately its present position, but the elongated shape of the rest of the box still retained. One of these, called the *lyra da braccio*, could be described equally well as a stretched violin or a pinched fiddle.

It appears that the violin shape settled down into its present one – deeply cut waist and wider but shorter broad parts – gradually, in a series of experiments by Andreas Amati, who came to Cremona about 1550. A surviving instrument by him dated 1574 is virtually indistinguishable, except by a trained eye, from the violins being made today (it is slightly smaller and therefore, for a reason we shall see presently, thin–toned). Some ninety years later, Antonius Stradivarius learned his trade as a young boy apprenticed to Andreas' grandson, Nicholas Amati.

It might be thought – and doubtless the early experimenters feared – that this shape of the violin would ruin the tone quality, by making it too "stiff". Fortunately, the opposite turned out to be true; in fact, the deep, rich tone on the g–string is assisted by that narrow waist. It is now well known (Benade, 1990, pp. 531–535) that the tone depends chiefly on the pitch of the various resonances of the instrument. For the moment, let us just say that a 'resonance' is a pitch at which something in the instrument (string, body, or enclosed air) vibrates of its own accord when the instrument is disturbed from rest.

You can hear the deepest resonances by damping the strings with your fingers (so their own resonances will not obscure matters) and snapping the back of the violin with your fingernail, noting how much the sound varies with the snapping point. The sound is a dull thud, but with a definitely recognizable pitch. The deepest tone thus heard is produced by snapping under the g–string end of the bridge. This is the "breathing mode" air resonance in which air flows alternately in through both f–holes, then out through both; in the modern violin it is near C$\sharp$ just above middle C, and this gives the violin its deep tone – and willingness to speak out loudly – on the g–string.

Mathematical analysis, performed by the great physicists Hermann von Helmholtz and Lord Rayleigh in the late nineteenth Century, shows that the pitch of this deepest air resonance depends almost entirely, not on its shape or stiffness but on the air volume of the box and the area of its f–holes; so the waist does no harm to it. The viola, with a slightly greater air volume, has this resonance about a whole tone lower; and this is the main reason for its different tone.⋆

But if you snap the back just under the sound post (approximately the e–string end of the bridge), you hear what at first seems to be a higher tone; but on careful listening

⋆ This can be demonstrated rather dramatically by making a violin produce a viola tone; merely fill it with carbon dioxide gas instead of air, from a rubber tube inserted into an f–hole. The sound velocity in pure carbon dioxide is 21% slower than in air, and this lowers the pitch of all air vibration modes by about a minor third. With a mixture of 2/3 carbon dioxide and 1/3 air the lowering is about a whole tone (there is no danger to the violin from this; in fact, a violin could be preserved intact for centuries by storing it in carbon dioxide, because it is chemically inert; with no free oxygen present the wood could not rot. However, pure nitrogen would be an even better preservative than carbon dioxide).

one perceives that the lowest tone present is still that C♯ of the breathing mode; only now it is so much weaker that other resonances can be heard. Most important is the second deepest resonance, in which the air sloshes back and forth between the broad sections. The narrow waist affects this mode a great deal, by impeding the flow and lowering its pitch down almost to A 440, which helps to enhance that deep tone.

The third air resonance is the "sideways" mode, in which the air sloshes back and forth between the left and right sides of the violin, thus flowing out of one f–hole while flowing in the other. The narrow waist raises the pitch of this mode appreciably (over what a box with no waist would show), but it is so high (nearly two octaves above middle C) that it plays no role in the deep tone anyway.

The still higher resonances of air and wood, which give the violin its brilliant tone quality, depend for their fine details on fine details of its shape and the stiffness of the purfling; but these are many dozens of these, so numerous and close and overlapping that their effects average out and the net result depends very little on the exact size and shape. Thus the box shape and dimensions affect the violin's tone mostly through their effect on the lowest two air resonances. Of course, this is only one of many considerations that a violin maker has to take into account; others concern the rigidity of the glued joints, which affects those resonances in which they bend, the exact shape and thickness of the wood under the bridge and the position of the sound–post, which affect the efficiency of transfer of vibrations from bridge to body, *etc.*

The important acoustical function performed by the resonant modes, helped inadvertently by that narrow waist, can be appreciated by comparing the aforementioned sound of a snapped violin with that of a large (12 inch) skillet held loosely by its handle and snapped by your finger. The lowest resonance of the skillet turns out to be almost the same as that of the violin; but for the skillet the next higher resonance mode is not at A 440 but nearly two octaves higher; the absence of anything in between makes the difference in what you hear.

A little is known about details of the final stages of development of the violin, because Antonius Stradivarius is so recent that many of his records – particularly the drawings and templates from which he made his instruments – have survived and may be seen in the museum in Cremona. It appears that he kept experimenting all his life; having found a particularly good design he might stick to it for a few instruments, but then would try a new design, altering some dimension a little bit to see what effect this had on the quality. Among other things, he was moving those resonances about slightly, fine–tuning them. For a good (and loud) tone he had to get those two lowest air resonances down a bit lower than in previous instruments, but if they were too low he would start to get a viola tone instead.

Of course, Stradivarius was not successful in all his experiments; indeed, if he had been, he would have learned nothing from them. Over his long life ($\simeq$ 1644 – 1737) he made some 1200 violins, and in every period there were some good, some bad. This is not a reflection on his craftsmanship, but simply evidence that he was still experimenting; it was only from getting a bad instrument that he could learn that he had carried some change too far.

But now the scene shifts to 250 years later: which violins are still in existence? The best ones have been preserved lovingly and kept in good repair by generations of good musicians; the worst have been destroyed by little boys who did not want to practice on them. The reputation of any craftsman is helped if he can be judged merely from his works that are still around 250 years later.

Early Keyboard Instruments

The known history of the organ is given by Sumner (1952). The hydraulic organ of Ctesibus, developed at Alexandria (2nd. Century B. C.) is depicted on some Roman coins. Unfortunately, they show little detail and we are left in doubt about what kind of keyboard it had, although it seems almost impossible that it could have been played without one. But keyboards with pivoted keys like our modern ones are described in the *Hydraulicon* of Vitruvius (1st Century A. D.). Keyboards were applied also to stringed instruments of the hurdy–gurdy[†] type before the 11'th Century.

A small portable organ called the *Regal* is described by many writers in and before the 12'th Century. By the 12'th Century it had become a product so standardized that tables were available for builders, with the correct dimensions to make the pipes for proper tuning. We know this from early 12'th Century manuscripts by one *Theophilus*, which is believed to be the pseudonym of a famous metal–worker, the Benedictine Monk Roger of Helmarshausen who flourished about 1100 AD; some of his works have survived to our time.[‡] Theophilus describes in great detail the process of making these organs; the pipes were made of copper pounded into thin sheets, wrapped around a tapered iron mandrel and soldered along the seam. He also gives detailed instructions for casting sets of tuned bells; to justify all the special jigs, mandrels, and templates needed to make these instruments, they must have been in something like mass production. Indeed, another 12'th Century manuscript[⋆] has an illustration of a group of musicians playing such an organ, together with tuned bells, a lyre, and a trumpet. The organ encompassed only about one octave, and had keys rather like modern cash–register keys.

Although the oldest are long gone, fairly old organs are available for study in churches all over Europe, so there is no question about how they were built after they had become nearly perfected and reached their present size. The full chromatic scale appears to be already in existence in the great Halberstadt organ, built in 1361, although its tuning was doubtless different from those of today. On these grounds, and the absence of any evidence for keyboard instruments in the Orient in early times, we may suppose that keyboard instruments are European inventions, not migrations from the East. For many more details about the great variety of the earliest keyboard instruments, see Wier (1940).

[†] These were played by turning a crank, which caused an abrasive wheel to scrape against whatever strings were lowered to contact it. The aforementioned "Lark in the Morning" catalog has illustrations of ten different hurdy–gurdy instruments still available today.

[‡] An English translation of the Theophilus manuscripts, with historical commentary, is in Theophilus (1963), which also contains photographs of some works of Roger of Helmarshausen.

[⋆] This is in the library of St. John's College, Cambridge, England; Manuscript B 18, fol. I.