his apprentice. In his own drawing, Leonardo eliminated a large-jawed animal that Verrocchio had perched atop the helmet, turned the dragon into swirls of plants, and generally made the design less complicated. "What Leonardo's simplifications achieved was to make the beholder's eye focus on the profile heads of the warrior and lion, i.e., on the relationship between the man and the animal," according to Martin Kemp and Juliana Barone.[36]

As with his paired carvings of Darius and Alexander, Verrocchio occasionally juxtaposed a profile of a craggy old warrior with that of a pretty boy, a theme that would become a favorite of Leonardo's, both in his drawings and in random notebook doodles. One example is in Verrocchio's *Beheading of Saint John the Baptist*, a silver relief he did for Florence's Baptistery, where a young warrior and an old one are juxtaposed on the far right. By the time this sculpture was made, starting around 1477, when Leonardo was twenty-five, it is unclear who was influencing whom; the young and old warriors facing each other, as well as an angelic young boy on the far left, have the vibrant movement and emotion-laden facial expressions that make it seem possible Leonardo had a hand in them.[37]

PAGEANTS AND PLAYS

For the artists and engineers in Florence's bottegas, working on the Medici pageants and spectacles was a significant component of their job. For Leonardo it was also a joy. He was already making a name as a colorful dresser, fond of brocade doublets and rose tunics, and as a showman adept at imaginative theatrics. Over the years, both in Florence and especially after he moved to Milan, he spent time devising costumes, theatrical scenery, stage machinery, special effects, floats, banners, and entertainments. His theatrical productions were ephemeral, and they linger only in sketches in his notebooks. They can be dismissed as diversions, but they were also an enjoyable way for him to combine art and engineering, and thus they became a formative influence on his personality.[38]

The artisans who created the sets for theatrical events became masters of the rules of artistic perspective that had been refined in the

1400s. The painted scenery and backdrops had to be unified with the three-dimensional stage settings, props, moving objects, and actors. Reality and illusions were blended. We can see the influence of these plays and pageants on both Leonardo's art and his engineering. He studied how to make the rules of perspective work for different vantage points, loved mixing illusion with reality, and delighted in devising the special effects, costumes, scenery, and theatrical machinery. All of this helps to explain many of the sketches and fantasy writings in his notebooks that scholars sometimes find mystifying.

For example, some of the gears and cranks and mechanisms that Leonardo rendered in his notebooks were, I think, theatrical machinery that he encountered or contrived. Florentine impresarios had created ingenious mechanisms, called *ingegni*, for changing scenery, propelling dazzling props, and turning stages into living paintings. Vasari praises a Florentine carpenter and engineer who climaxed a festival show with a scene of "Christ carried upward from a mountain carved of wood and borne to heaven by a cloud filled with angels."

Likewise, some of the flying contraptions that we find in Leonardo's notebooks were probably for the amusement of theatrical audiences. The Florentine plays often involved characters and props descending from the heavens or being magically suspended in air. Some of Leonardo's flying machines were, as we will see, clearly aimed at real human flight. Others, however, are on notebook pages from the 1480s and seem to have a theatrical purpose. They feature wings with limited range moved by cranks, and they could not possibly have been propelled into the skies by a human pilot. Similar pages include notes on how to project lights onto a scene and drawings of a hook-and-pulley system to raise actors.[39]

Even Leonardo's famous drawing of an aerial screw (fig. 6), often touted as the design for the first helicopter, falls into this category of *ingegni* devised for a theatrical spectacle, I believe. Its spiral mechanism of linen, wire, and cane was, in theory, supposed to turn and bore upward into the air. Leonardo specified certain details, like making sure the linen has "its pores stopped up with starch," but he showed no method for a human to operate it. It is big enough to be amusing but probably not enough to carry a human. In one model,

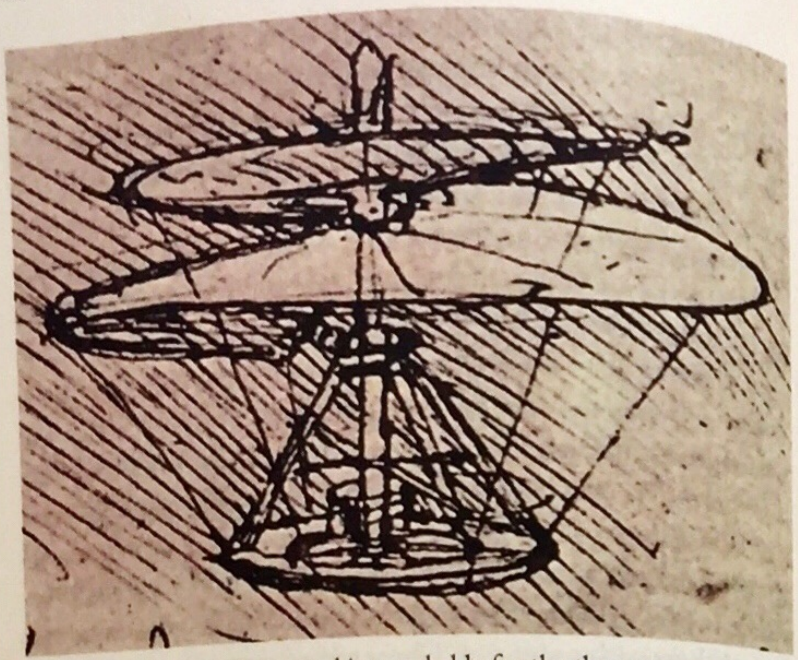

Fig. 6. A flying machine, probably for the theater.

he specified that the "axis will be made of a fine steel blade, bent by force, and when released it will turn the screw." There were toys at the time that used similar mechanisms. Like some of his mechanical birds, the aerial screw was probably made to transport spectators' imaginations rather than their bodies.[40]

THE ARNO LANDSCAPE

Leonardo enjoyed the collegial and familial atmosphere in Verrocchio's workshop so much that, when his apprenticeship ended in 1472, at the age of twenty, he decided to continue to work and live there. He remained on friendly terms with his father, who lived nearby with his second wife and still had no other children. When Leonardo registered as a member of the Florentine painters' confraternity, the Compagnia di San Luca, he affirmed his relationship by signing himself "Leonardo di Ser Piero da Vinci."

The Compagnia was not a guild but a club-like mutual aid society or fraternity. Other members who registered and paid dues in 1472

included Botticelli, Pietro Perugino, Ghirlandaio, Pollaiuolo, Filippino Lippi, and Verrocchio himself.[41] The Compagnia had been in existence for a century, but it was undergoing a revitalization partly because artists were reacting against Florence's antiquated guild system. Under the old guild structure, they were lumped into the Arte dei Medici e Speziali, which had been founded in 1197 for physicians and pharmacists. By the late 1400s they were eager to assert a more distinctive status for themselves.

Months after becoming a master painter, Leonardo escaped the bustling narrow streets and crammed workshops of Florence and took a trip back to the rolling green hills around Vinci. "I, staying with Antonio, am contented," he scribbled in his notebook in the summer of 1473, when he was twenty-one.[42] His grandfather Antonio had died, so the reference is perhaps to his mother's husband, Antonio Buti (Accattabriga). One can picture him content as he stays with his mother and his large stepfamily in the hills just outside of Vinci; it conjures up his tale of the stone that willed itself to roll down to the crowded road but later yearned to be back up on the quiet hill.

On the reverse of that notebook page is what may be Leonardo's earliest surviving art drawing, the shimmering start of a career of combining scientific observation with artistic sensibility (fig. 7). In his mirror script he has dated it "day of Holy Mary of the Snows on the 5th August 1473."[43] The drawing is an impressionistic panorama, sketched with quick pen strokes on paper, evoking the rocky hills and verdant valley surrounding the Arno River near Vinci. There are a few familiar landmarks from the area—a conical hill, perhaps a castle—but the aerial view seems to be, typical of Leonardo, a mix of the actual and the imagined, viewed as if by a soaring bird. The glory of being an artist, he realized, was that reality should inform but not constrain. "If the painter wishes to see beauties that would enrapture him, he is master of their production," he wrote. "If he seeks valleys, if he wants to disclose great expanses of countryside from the summits of mountains, and if he subsequently wishes to see the horizon of the sea, he is lord of all of them."[44]

Other artists had drawn landscapes as backdrops, but Leonardo

its armature is eighty feet across, and so is the carriage that would roll it onto the battlefield. To put it in perspective, he shows the weapon dwarfing a soldier who is preparing to unleash the trigger.

Leonardo was a pioneer in propounding laws of proportion: how one quantity, such as force, rises in proportion to another, such as the length of a lever. A super-sized crossbow should, he correctly surmised, be able to hurl projectiles that were bigger or went farther. He tried to figure out the correlation between the distance the bowstring was pulled and the force it exerted on the projectile. At first he thought that a bowstring pulled back twice as far would exert twice the force. But he realized that rate was thrown off by the bending of the bow as the string was pulled. After various calculations, he finally concluded that the force is proportional to the angle of the string at the point where it is pulled back. Pull the string back hard, and it will make (say) a 90-degree angle; pull back even harder, and perhaps you can get the angle down to 45 degrees. A 45-degree angle, he theorized, would deliver twice the force of 90 degrees. That doesn't turn out to be exactly right; Leonardo did not know trigonometry and thus couldn't refine the theory. But in concept he was close. He was learning to use geometric shapes as analogues for nature's forces.

In Leonardo's design, the bow was to be made with interlocking layers of wood, an early example of lamination. That would make it flexible, springy, and less likely to crack. Its string was pulled back by ropes attached to a large gear-and-screw mechanism, which he detailed in a side drawing. Cocked in such a fashion, he wrote, the device should be able to fling "one hundred pounds of stones." Gunpowder was in common use by then, which would seem to make a mechanical crossbow obsolete. However, if the crossbow had worked, it could have been cheaper, easier, and certainly quieter than cannons using gunpowder.

As with the scythed chariot, a question arises: How serious was Leonardo? Was he merely being clever on paper and trying to impress Ludovico? Was the giant crossbow another example of his ingenuity blurring into fantasy? I believe his proposal was serious. He made more than thirty preparatory drawings, and he detailed with precision the gears, worm screws, shafts, triggers, and other mechanisms. Nevertheless, the crossbow should be classified as a work of imagination rather than invention. It was never constructed by Ludovico Sforza. When it was finally built for a television special in 2002, the contemporary engineers were unable to get it to work. During his career, Leonardo would be known for paintings, monuments, and inventions that he conceived but never brought to fruition. The giant crossbow falls into that category.[15]

That was also true, it turned out, for most of the military devices he conceived and drew during the 1480s. "I will make unassailable armored chariots," he promised in his letter to Ludovico. He did in fact design one, at least on paper. His drawing of an armored tank, which looks like a cross between a turtle and a flying saucer, shows metal plates slanted on an angle that would cause it to deflect enemy projectiles. Inside would be eight men, some of them turning cranks to cause the tank to inch ahead, the others firing cannons that project out in all directions. There is one design flaw: a careful look at the crank and gears shows that they would turn the front wheels and the back wheels in opposite directions. Did he draw it that way intentionally so that it could not be easily constructed without his modification? Perhaps. But the issue was moot; the machine was never built.

He had also promised Ludovico, "I will make cannons and artillery of beautiful and useful design that are different from those in common use." One such attempt was a steam cannon, or *architronito*, an idea that Leonardo attributed to Archimedes and that was also in Valturio's book. The concept was that the breach of a cannon would be heated in burning coals until it was super-hot, then a small amount of water would be injected just behind the cannon ball. If the ball was held in place for a second or so, enough steam pressure would build up to fire it a few hundred yards when released.[16] Another proposal he drew was for a machine with many cannons, one with racks of eleven cannons each. While one set of cannons was cooling off and being reloaded, the other sets could be firing. It was the precursor to the machine gun.[17]

Only one of Leonardo's military conceptions is known to have made it off the pages of his notebooks and onto the battlefield, and he arguably deserves priority as its inventor. The wheellock, or wheel