Advanced NXT

The Da Vinci Inventions Book

Matthias Paul Scholz

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ISBN-13 (pbk): 978-1-59059-843-6

ISBN-10 (pbk): 1-59059-843-1

Printed and bound in the United States of America 9 8 7 6 5 4 3 2 1

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Distributed to the book trade worldwide by Springer-Verlag New York, Inc., 233 Spring Street, 6th Floor, New York, NY 10013. Phone 1-800-SPRINGER, fax 201-348-4505, e-mail `orders-ny@springer-sbm.com`, or visit `http://www.springeronline.com`.

For information on translations, please contact Apress directly at 2855 Telegraph Avenue, Suite 600, Berkeley, CA 94705. Phone 510-549-5930, fax 510-549-5939, e-mail `info@apress.com`, or visit `http://www.apress.com`.

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To the memory of Stanislaw Lem (1921–2006)

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About the Author

MATTHIAS PAUL SCHOLZ has a degree in mathematics obtained at the University of Bayreuth, Germany, and works presently as a system engineer. He has held IT-related positions in various companies in Germany over the past 12 years, specializing in model-driven development and distributed environments. He has been an active member of the LEGO MINDSTORMS community since 2000. Scholz was one of the developers of the open source leJOS platform for the RCX, took part in the LEGO MINDSTORMS Developer Program, and is presently one of the 20 members of the LEGO MINDSTORMS Community Partners Program. Furthermore, he is one of the contributors to the popular The NXT STEP blog and maintains the German-language sister blog, Die NXTe Ebene. His own MINDSTORMS NXT-related web site is at `http://mynxt.matthiaspaulscholz.eu`.

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Acknowledgments

First of all, I would like to thank my most amiable wife for her support and patience with all the evening, late-night, and weekend hours I spent on the book in the past months.

Special and very cordial thanks go to Jim Kelly who encouraged me to write this book, opened doors for me, and not only provided warmhearted guidance and indispensable advice but also acted as a tech editor for the book.

Also, I'd like to thank all the other aficionados out there whose commitment and mad rapture for LEGO MINDSTORMS NXT filled me with the energy to complete all the work for the book. In particular, I'd like to mention Steven Canvin from LEGO, Maureen Reilly from NXTLOG, Brian Davis, Steve Hassenplug, Philo, and The NXT STEP gang. Thanks also to the guys from the leJOS NXJ project, John Hansen for NXC, Ralph Hempel for pbLua, and Daniele Benedettelli and Lukas Probst for their tutorials. These people are only a small section of all the enthusiastic LEGO weirdos that form a bustling community I'm proud to be a part of. Please bear with me if I forgot to name someone who particularly deserves it.

I am amazed and grateful for the work done by the production team for this book, in particular Kylie, Jennifer, and Laura from Apress, who did a prodigious job, and I'd like to voice my particular gratitude for being that dedicated and so very patient with me.

Preface

Robots have been a source of fascination to me since my childhood. That was during the time of the first *Star Wars* trilogy, with very humanlike robots appearing on the screen, such as C-3PO, who still reminds me of some friends of mine, and not so humanlike others, such as R2-D2 (who nevertheless also reminds me of some people I know). There were the books of Stanislaw Lem and Douglas Adams that discuss the philosophical questions related to the creation of artificial beings. Do androids dream of electric sheep? I still wonder.

Yet all my attempts to build something similar on my own failed. The gizmos I'd assembled from wood and plastic not only looked strangely different from the ones I had in mind, but also didn't do anything (besides fall apart frequently). The time was not ripe for building robots of your own, unless you had a degree in electronic engineering, high soldering capabilities, and a well-endowed bank account to acquire all the special electromechanical parts required.

This all changed dramatically when in 1998 the LEGO Group released the LEGO MINDSTORMS system. At once it was possible to build robots with a technology that I and almost everyone else I knew was used to since childhood: LEGO bricks. In fact, I considered LEGO to be only a toy then and my trunk full of bricks had long ago changed possession to my little brother. But it didn't take long to realize the potential of the new product line. I was even more surprised to find out that there was a MINDSTORMS community out there that to a large part was composed of people of my age, my professional IT background, and my interest in technics, in particular in robotics. Consequently, I bought some of the kits and expansions and indulged in the open source movement that was rapidly growing and bustling with energy. That is, I became one of the developers of the leJOS project, dedicated to providing a Java implementation for the MINDSTORMS RCX Brick.

So the millennium went by with creating robots and trying to overcome the limitations of the RCX, whose technical parameters were already outdated in 1998. An update was overdue, but instead, the kits were beginning to disappear from the shops and it seemed that LEGO was resting on the laurels of MINDSTORMS, which had developed into the best-selling product in the company's history.

Fortunately that wasn't the case at all.

In 2005, rumors began to spread that a successor to the RCX was to be expected. Indeed, LEGO announced the MINDSTORMS Developer Program (MDP) and asked for applications. I instantly jumped in—without much hope—as virtually everyone I knew in the community did the same. How great, though, was my joy when I received a confirmation that I was to be one of the blessed 100? As a matter of fact, I didn't believe it in the beginning, suspecting that it was just a cruel joke by my friends.

It wasn't, and what was to follow were months of fun, devotion, and creative energy. The days had not enough hours and the kits not enough parts to implement all the ideas that were appearing in my head and in those of the most interesting and different people I've met in the program. Well, one needs to bring home the bacon, but I realized then how tedious your (otherwise satisfying) everyday job is able to appear when you long to race home and complete the time machine you are tinkering with.

One of the ideas that arose rather early was to combine my NXT-related activities with another topic of interest to me—medieval history. It was only a small step to notice that the mechanical works of one of the greatest engineers ever, Leonardo da Vinci, would suit the subject tremendously well. However, I never dreamt of really writing a book on it, and most likely it wouldn't have come into being if Jim Kelly—whom I'm proud to be connected to by the MDP, the blog we both write for, and last but not least, the books in this MINDSTORMS series—hadn't encouraged me to do so.

Hence, here it is. I hope you enjoy it.

Who This Book Is For

This book is about building quite complex LEGO NXT robots with a lot of different parts. You will learn techniques to master certain challenges in building real-world gadgets with LEGO and how to make best or at least good use of special parts that are contained in the NXT kit or in other ones. You also should get a feeling for how to transform contraptions from the "real" world into LEGO devices and how to use the motors and various sensors the NXT kit provides.

That said, some of the robots are rather sophisticated and comprise a lot of different parts that are arranged in a sometimes complicated manner. Therefore, absolute beginners who do not feel at least basically at ease with LEGO TECHNIC and studless building might prefer to make themselves familiar with these topics before trying to tackle the robots introduced in this book.

As for the software, a fundamental understanding of the basic principles of programming is recommended. I introduce five different environments for creating and running programs in the NXT, where almost each one is based in a particular development paradigm. It goes without saying that there's always the option of concentrating on one single environment and leaving the others out; but even so, some experience with the programming paradigm in question—for instance, with object-oriented programming in the case of leJOS—might prove useful. Also, when it comes to the software, programming newbies might wish to address some tutorials before implementing the programs in the book.

For the NXT environments used in the book, though, no previous knowledge is required. I explain in detail not only their installation and configuration, but also the language constructs, which are displayed by example in a step-by-step manner.

In the end, you should be familiar with the strategies to implement standard challenges for NXT robots in the different languages and have an overview of the options available for programming the NXT and know which one best fits your background and taste.

How This Book Is Structured

This book is organized around chapters that recreate five inventions of Leonardo da Vinci using LEGO. Each of these chapters consists of the following:

- A lecture on the historical background
- A discussion of the hardware challenges the invention imposes on a LEGO model and the solution
- Complete step-by-step building instructions
- Programming instructions for each of the five programming environments the book uses

Chapter 1: Introduction

This chapter consists of a tour through Leonardo's life and five of his most famous inventions to be built with LEGO. It also introduces the NXT and its components and provides a glimpse of the NXT community and some of its most prominent sites.

Chapter 2: A 3,000-Foot Look at NXT Programming Environments

This chapter discusses the five different programming environments used in this book: the official LEGO MINDSTORMS NXT Software, RobotC, NXC, pbLua, and leJOS NXJ. It focuses on those that allow running programs directly on the Brick—autonomous robots rather than those confined to remote control from an external device such as a computer or a cell phone.

Chapter 3: The Armored Car

This chapter is the first robot chapter. It deals with Leonardo's design of an armored car, a machine like today's military tank. Like the following four chapters, it provides a historical background, a discussion of the LEGO hardware challenges and their solutions, the building instructions, and the programming of the robot with five different programming environments.

Chapter 4: The Catapult

This chapter introduces one of the catapults Leonardo designed and shows how to build it with LEGO. You will encounter the device he invented to set up kinetic energy and the touch sensor.

Chapter 5: The Revolving Bridge

This chapter shows how to build Leonardo's revolving bridge with LEGO. You will gain insight into motor synchronization and learn how to make use of the ultrasonic sensor.

Chapter 6: The Aerial Screw

This chapter presents a LEGO implementation of Leonardo's aerial screw, also—but misleadingly—known as the "helicopter." It's an introduction to mimicking curved structures and to the usage of the light sensor.

Chapter 7: The Flying Machine

This chapter showcases another machine invented by Leonardo for the purpose of flying and how to build it with LEGO. Its "flapping wings" make it different from the aerial screw. You will learn how to use wires to run mechanical parts and to remotely control a NXT robot.

Chapter 8: Outlook: What NXT?

This is a discussion of the conceivable steps the reader may take from here. It discusses possible refinements of the preceding five robots and the possibility of remotely controlling them. It sheds some light on other inventions of Leonardo's that might be created with LEGO, and finally introduces some web sites and books recommended for further reading.

Appendixes

This book contains four appendixes. The first provides step-by-step guides to the installation and configuration of the five different programming environments in this book. The second contains a copy of Leonardo's letter of application to the duke of Milan that is mentioned frequently in the book. The final two appendixes are a glossary and a bibliography.

Prerequisites

To complete the programming examples in the book, you will need five different programming environments for the NXT. The first one is contained in the retail version of the NXT kit, while the others are available on the Internet, either for free or as trial versions. Appendix A provides all the information you need to download, install, and configure them for this book.

Downloading the Code

The source code for this book is available to readers at the Apress web site at `http://www.apress.com` in the Source Code/Download section. You can also check for errata and find related titles from Apress.

Additional material related to the book such as updates, videos and more can be downloaded from my web site at `http://mynxt.matthiaspaulscholz.eu`.

Contacting the Author

If you are eager to contact me for feedback, questions, or suggestions, feel free to use the contact page on my web site at `http://mynxt.matthiaspaulscholz.eu/contact`. I always try to respond to any approach by a reader as soon as possible.

CHAPTER 1

Introduction

I have been impressed with the urgency of doing. Knowing is not enough; we must apply. Being willing is not enough; we must do.

—Leonardo da Vinci

This book is on two topics that at first glance may appear rather disconnected: Leonardo da Vinci and LEGO MINDSTORMS NXT. Yet, on reconsideration you might notice that not only do the stupendous mechanical designs of Leonardo have much in common with NXT robots, but so do Leonardo—the inventor and engineer—and modern NXT robot builders.

Leonardo's machines were based on established designs and existing mechanical parts but went beyond the tradition by combining high-technology components of his time with conceptual audacity and brilliant ingenuity, thus creating devices that aroused the admiration of his contemporaries as well as people today. Same goes for NXT robots and their creators—though certainly to a more minor extent. LEGO TECHNIC is a well-known and established way of building LEGO machines, while NXT may be justifiably considered as some kind of high-technology gadget. And already creations of stunning imaginativeness are appearing on the scene, pushing the possibilities of NXT robotics farther and farther beyond the limits.

So what stands more to reason than combining these two topics, thus bridging the centuries and reviving the thoughts of one of the most brilliant minds in mankind's history?

Most likely the majority of people know Leonardo as an artist, as the creator of such renowned works as the *Mona Lisa* or *The Last Supper*. But as you will see in the course of this chapter, his faculties, interests, and achievements were much more widespread.

You will take a look into Leonardo's life, examining five of his most prominent inventions. After that you will endeavor your first tour through the LEGO MINDSTORMS NXT universe.

Always keep in mind, though, that the following ramble can only provide a selection of the capabilities and achievements of this stupendous universal genius.

An Invention-Driven Tour Through the Life of Leonardo da Vinci

No doubt Leonardo di ser Piero da Vinci is one of the most ingenious men of modern history. Justifiably, he's also one of the most well-known: almost 500 years after his death, he hasn't ceased to arouse the imagination and admiration of contemporary people.

Media on Leonardo da Vinci is legion today (for a short selection, refer to the bibliography in Appendix D). To provide even an abstract of the many different aspects of his life, appreciating his capabilities on the areas of anatomy, art, and science, would decidedly be beyond the scope of this book. Instead, I will try to unveil his scientific career by throwing some highlights on a selection of his mechanical designs that may both serve as an illustration of the different fields of technological research he excelled in as well as help you approach his life and his way of thinking.

Renaissance Man

Like no other man, Leonardo personifies the *Renaissance*, a term meaning *rebirth* and denoting a time half a millennium ago when the focus of the Occident's highbrows shifted from metaphysical considerations to matters that from today's view may be considered "physical": interest in the human being itself; the scientific (rather than the philosophical) heritage of the antique; the different phenomena mankind encounters in nature; and the use of mechanical inventions for everyday life challenges. It's not without reason that the artwork that has become *the* symbol for the Renaissance is one of Leonardo's creations: *The Vitruvian Man* (Figure 1-1).

■ **Note** Giorgio Vasari, who wrote the first biography of Leonardo in his "Vite de' più eccelenti architettori, pittori e scultori italiani" ("The lives of the most excellent Italian architects, painters, and sculptors") in the 1550s, said that when famous Florentine artist Andrea del Verrochio saw Leonardo's work on the angel in *The Baptism of Christ*, he was so amazed that he resolved never to touch a brush again.

Even though there are other famous men such as Michelangelo, Albrecht Dürer, or Galilei Galileo who are connected to the Renaissance in the public mind, Leonardo da Vinci most likely represents more than anybody else the synthesis of all-embracing curiosity, open-mindedness, and ingenuity that characterized the Renaissance polymaths—qualities that seem to have become regrettably rare in today's fragmented scientific landscape.

■ **Note** Some other famous Renaissance artists such as Rafael and Michelangelo lived and worked in Rome when Leonardo moved there from Milan in 1513, but it seems Leonardo did not come into contact with them. Maybe he was too consumed with his own works then, as he had resumed his theoretical researches on the laws of optical reflection, in particular in connection with parabolic and concave mirrors. It is a topic he had come in contact with previously during his early apprentice years in Verrochio's workshop, where *concave mirrors*—collecting and amplifying the sun's light—were used for metallurgic purposes. It is said that it is here that Leonardo witnessed the welding of the two hemispheres to the golden ball that is located on top of the Florentine dome today.

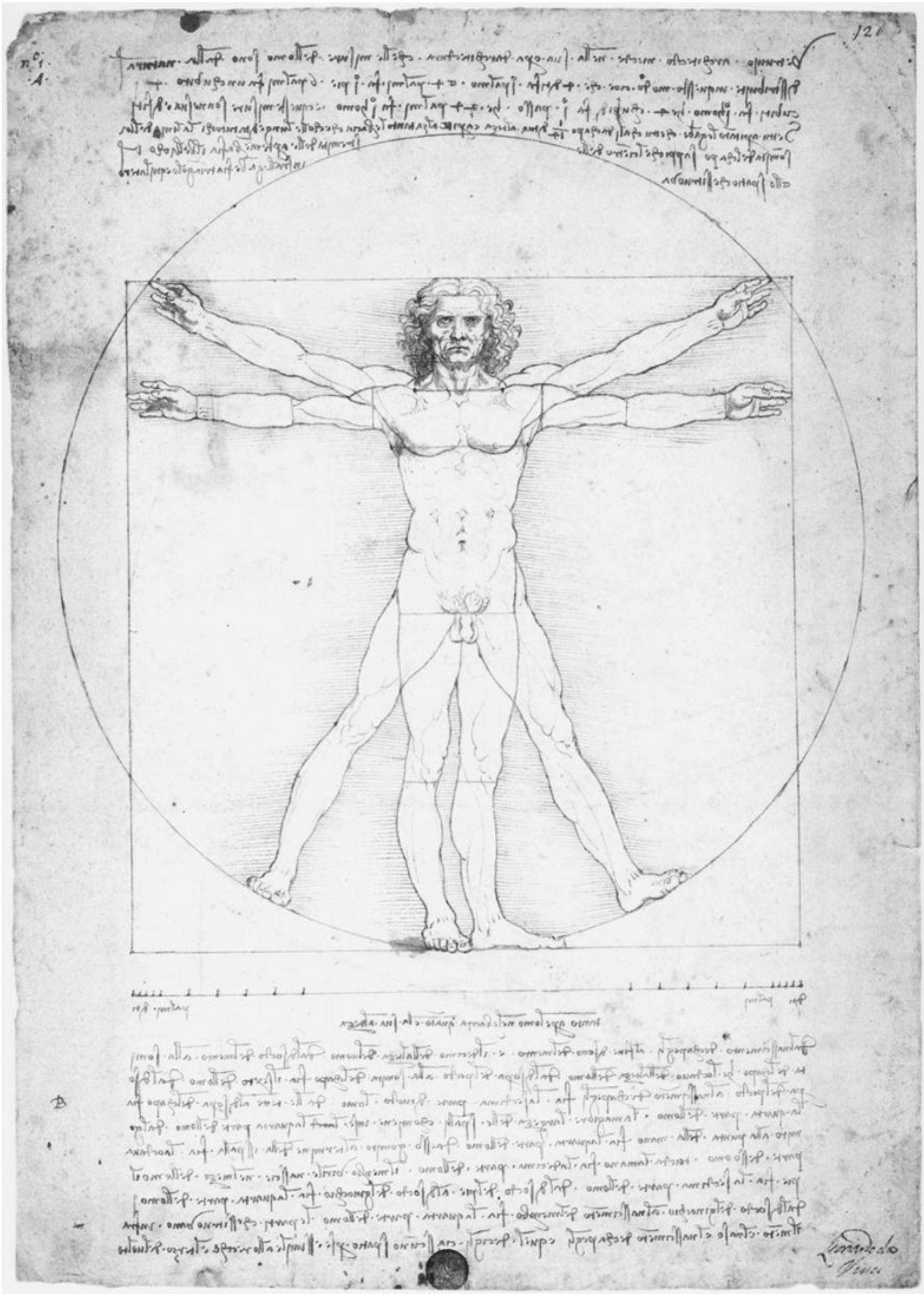


Figure 1-1. *The proportions of the human body in the manner of Vitruvius*

HISTORY OF LEONARDO

Leonardo spent much of his lifetime living in Milan. But he was no born Milanian; his place of birth on April 15, 1452, was Anciano, a small Tuscany village near Vinci, located in the vicinity of Florence.

It is popularly believed that his mother was a peasant woman to whom his father, the wealthy Florentine notary Piero, was not married. Though not uncommon these days, illegitimate children in most cases did not have it easy back then. However, Leonardo was lucky. His father brought him to live with him and his wife at Vinci when he was five years old. In 1460, the family moved to Florence. Here Leonardo most likely received an excellent education. His later claims of being "almost illiterate" may be considered as intentional understatements.

At age 14, he became a *garzone* (studio boy) in the workshop of the famous Florentine sculptor Andrea del Verrochio, a possible indication of the parental diligence toward him. Verrocchio today is most well-known for his impressive equestrian statue of Bartolomeo Colleoni in Venice, but his workshop in Florence processed orders in many different areas: painting, bronze statues, bells, construction machines for the building of the Florentine dome, mechanical theater gadgets, metallurgic works, and armory. It was here where Leonardo started to develop his interest in military devices, though he was nominally employed as a painting apprentice, where he obviously excelled as well.

By 1482 when he left Florence for Milan, Leonardo was an independent master. In 1498, the French conquered the Duchy of Milan, driving the Sforzas out of power. Leonardo stayed there for one more year and left in 1499. It has been said that the reason for this decision was because the French archers used his life-size clay model of his planned *Gran Cavallo* horse statue for target practice. As a matter of fact, it was not the first time his artistic plans had been impacted by the war; in 1495, 70 tons of bronze that had been set aside for the *Gran Cavallo* was instead cast into weapons for the duke during a previous French assault.

After Leonardo returned to Milan in 1508, he was again driven away when in 1513 Swiss mercenaries hired by the city's patricians drove out the French. Leonardo moved to Rome where Giovanni di Medici, the son of the former Florentine sovereign Lorenzo (Lorenzo eventually became the infamous Pope Leo X), instructed his brother Guiliano to gain valuable acreage by draining the Paludi Pontine (Pontinian swamps) south of the Eternal City. Guiliano was happy to engage Leonardo for this sophisticated project.

Leonardo obviously had deeply impressed his French employers during his second stay in Milan. In 1517, the French King Francois I (nicknamed "le Roi-Chevalier," the Knight King) invited him to France to work as his first royal engineer. Leonardo moved into the manor house Clos Lucé, also called "Cloux," which was located next to the king's residence at the royal Chateau Amboise and which is a museum today open to the public. The king was a genuine admirer of his new first engineer ("No man had ever lived who had learned as much about sculpture, painting, and architecture, but still more that he was a very great philosopher," as he said), and eventually the two men became friends, though very unequal in age (Francois was 42 years younger).

Francois granted Leonardo and his assistants generous pensions that enabled Leonardo to concentrate on his theoretical studies about flying in his last two years of life. Now and then he performed some jobs also for the court that aroused stunned admiration—hydraulic systems for fountains, for instance, or, on the occasion of a visit of Florentine merchantmen, a mechanical lion (the symbol of Florence) that automatically opened its breast to spread lilies (the symbol of the French crown) on the delighted audience.

Leonardo died May 2, 1519, in the arms of King Francois. His remains were later moved to the chapel of Saint Hubert inside the castle; however, there is no longer any trace of them today, as many tombs were destroyed during the 16th century Wars of Religion.

Five Designs

This section explains the five designs you will build in this book:

- The armored car
- The catapult

- The revolving bridge
- The aerial screw
- The flying machine

The Armored Car

The armored car is one of Leonardo's most well-known designs. As with all of his inventions, it came to us by drawings produced by Leonardo himself, an exceptionally gifted draftsman. The armored car resembles the concept of the military tank invented at the beginning of the 20th century (Figure 1-2).

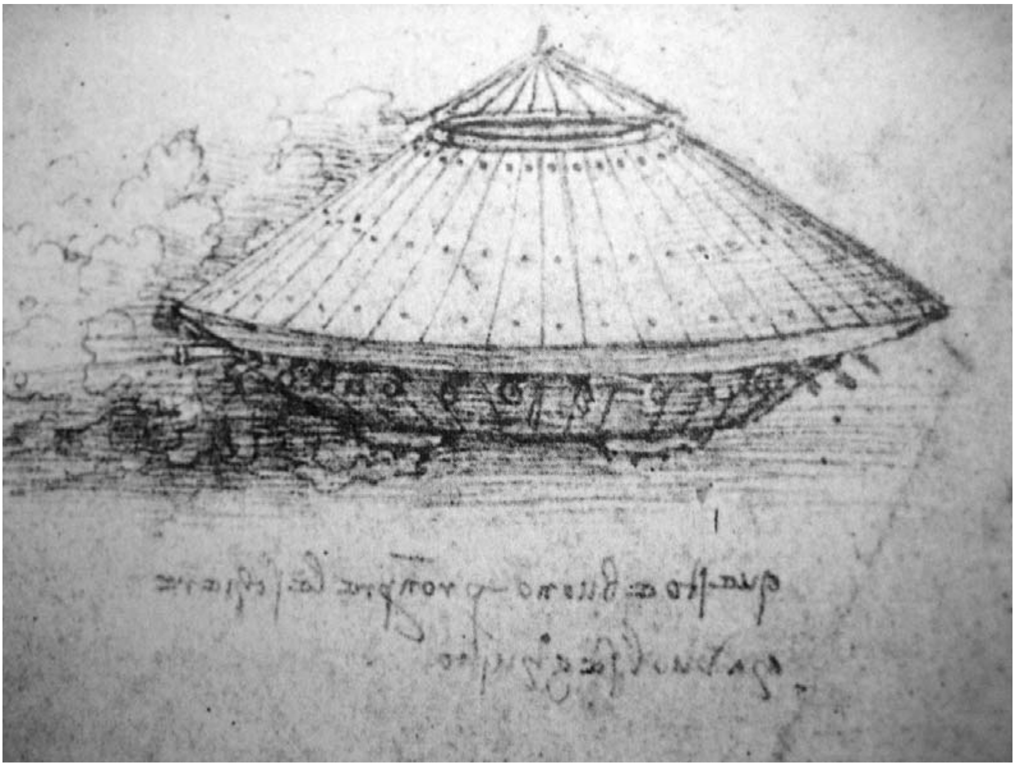


Figure 1-2. *The armored car*

Leonardo apparently drew this sketch between 1482 and 1485 when he was living in Milan for the first time. The drawing of the armored car may have been attached to a letter that Leonardo wrote or had had written (in the times of no word-processing software it was common to have important documents written by a paid expert) to the Duke of Milan, Ludovico Sforza, nicknamed "Il Moro," as an application of employment. Appendix B contains a translation of the complete text of this letter of application. Though we do not know the reception it got, machines of war were undoubtedly of major interest to a North-Italian sovereign in the politically unstable last decades of the 15th century. In the case of Ludovico that interest decidedly was a valid one, as the French drove the Sforzas out of Milan only some years later.

We may wonder about Leonardo's dealings in military aspects and may even find it reprehensible, but we must not forget that at this time, war was not considered unethical but rather was looked at as some kind of art—at least by those who did not directly suffer from it. Furthermore, it squared with the interest of the Renaissance engineers in technical methods, as machines of war were among the most complex classical devices. And last but not least, the rulers were willing to spend incredible sums for military technique—not unlike today—but even more interesting to engineers, potentates were the most important employers of their profession in times when unemployment insurance did not exist.

The Catapult

Leonardo's work on the catapult is another example of his interest in military devices. In contrast to the scientists in the medieval times, he did not confine himself to just copying the classical knowledge but used it as a base for enhancements and amendments, true to Newton's famous citation "If I have seen further it is by standing on ye shoulders of Giants" 200 hundred years later. Such is the case with the catapult; Leonardo invented a new spring mechanism that could generate higher energy for throwing projectiles farther (Figure 1-3).

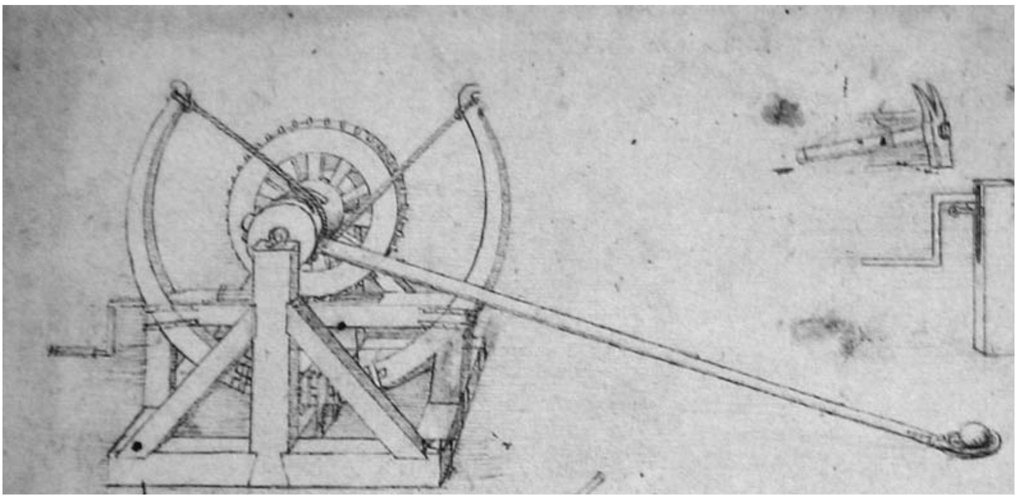


Figure 1-3. *The catapult*

Though fire weapons had already been established by the end of the 15th century and had found their way onto the European battlefields, they still suffered from a lot of "teething troubles." Hence, the well-proven concept of catapults was widely used, particularly at sieges where their multiple advantages—ease of use, high firing rate, high range, and the ability to launch a wide variety of different projectiles—provided a gain against cannons when using artillery against fortresses.

Leonardo made many designs for different types of catapults during his life, many of them during his early Florentine years. The one in question appears to have been produced during the first years of his work for Ludovico Sforza in Milan. It may have also been attached to the letter of application with the armored car.

We do not know how many of his military designs during his time in Milan made it into real deployment. Technical difficulties, impracticalities, and the fact that Leonardo was not employed by the duke as a military engineer but as the director of parades and festivities, might imply that many of his plans never left the theoretical stage. It's also possible the duke was not able to recognize the significance of Leonardo's designs and may have preferred other more practical and traditional competitors for the job. After all, Leonardo's position enabled him to run his own workshop alongside some apprentices. This gave him the opportunity to continue his studies without too many financial worries. During this time period, six major paintings, including *The Last Supper*, and a flood of technical drawings were created.

The manuscript for the catapult is part of Leonardo's Codex Atlanticus, which is preserved in the Biblioteca Ambrosiana in Milan. Many of Leonardo's drawings are collected in *codices*, collections of loose papers compiled by different collectors over the centuries. In most cases they are arranged not according to their original chronological order but, as was the custom in earlier periods, by a topical or even aesthetical scheme.

Note These codices are today distributed over the museums of the world. For example, the Codex Leicester, a folio of scientific observations and illustrations on natural phenomena such as water, light, and gravity, was acquired by Microsoft's founder Bill Gates in 1994 and is put on public display once a year in a different city around the world. In 2007, it will be exhibited from June to August in the Chester Beatty Library in Dublin, Ireland.

The Revolving Bridge

The revolving bridge is contained in another manuscript that came to us with the Codex Atlanticus. It's an example of another area of Leonardo's interest: *hydrodynamics*, the science of the flow of water (Figure 1-4).

Leonardo dealt with studies on this topic during almost all of his scientific life. He believed water and air are similar substances and thus follow similar laws of flow. This was a surprisingly modern approach and was of particular interest to him in regard to his research on human flying, which you will read about in a later section.

Fortunately for him (and for the world), this interest squared perfectly with a practical need of his time: water was one of the major sources of energy then. The north Italian plain was plastered with water mills in these times. Furthermore, the rare roads were in bad shape and were more like paths than anything else. Hence, rivers and the sea were of utmost importance for transportation of goods and people.

As a consequence, cities such as Florence and Milan, with no direct access to the sea, were keen to spend a great deal of financial and material resources on making use of the rivers and any evolving engineering disciplines.

In Florence, young Leonardo was engaged in a canal project to make the Arno river navigable from Florence to the Mediterranean Sea. He was the first to propose this enhancement, according to Giorgio Vasari, the writer of Leonardo's first biography. In Milan, Leonardo made further contact with hydraulic engineering, learning a lot about it from Milan's impressive set of the so-called *navagli*, a network of inner-city canals. These experiences proved helpful when Leonardo turned his attention toward another water-related topic of even more military importance than today: bridges.

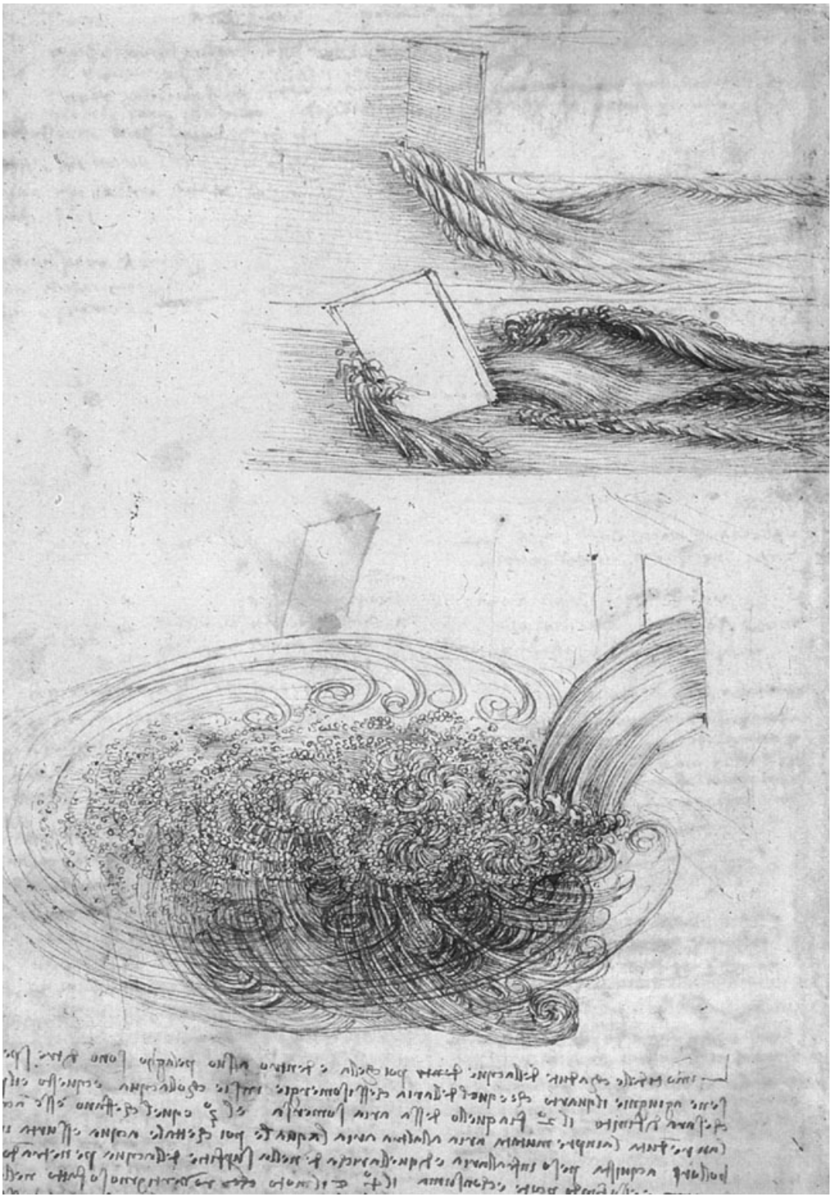


Figure 1-4. *Hydrodynamic study*

As cross points between streets and rivers, the two thoroughfares of transportation, bridges were of paramount relevance in military strategies. Bridges formed bottlenecks that could detain enemy troops. But this advantage could also be turned into a disadvantage if the enemy got a hold of the structure. Toward the end of his first decade in Milan, Leonardo developed a simple but effective concept to cope with this hazard: the revolving bridge. In his design, the bridge can be rotated around one of its end pylons (Figure 1-5). This way it could be moved away from the bank the enemy troops were approaching from, depriving them of the possibility to cross the river.

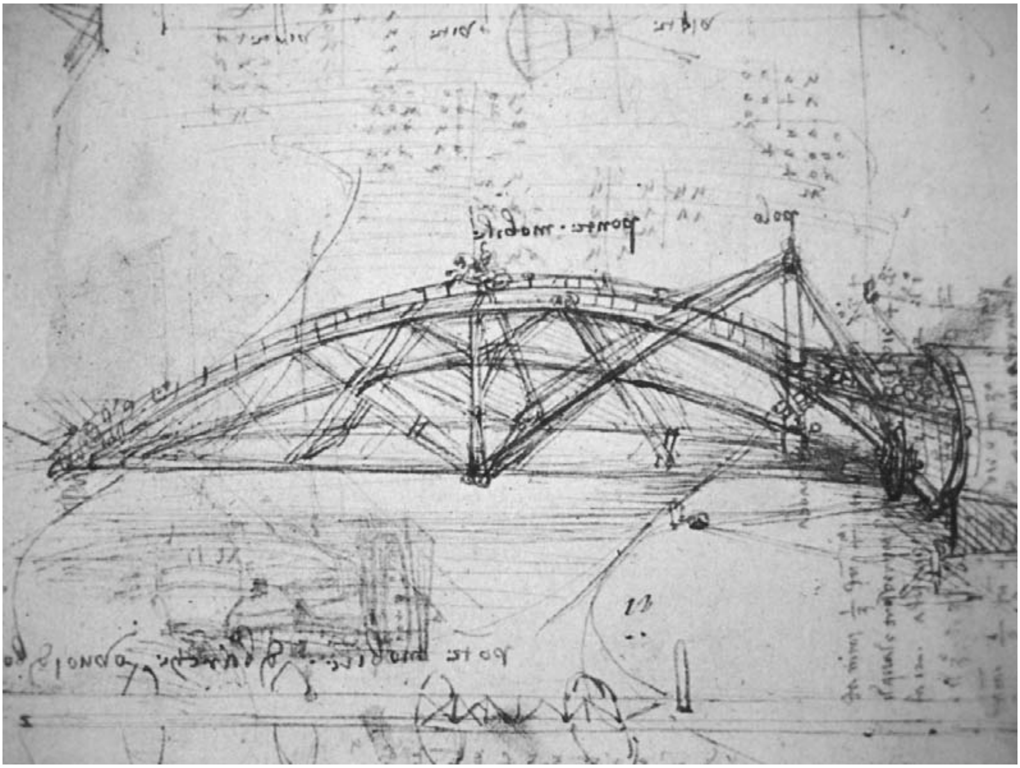


Figure 1-5. *The revolving bridge*

It is not known, though, if this bridge was ever been built somewhere around Milan.

When Leonardo left the city in 1499, he took his hydraulic knowledge with him and after three years of travel where he worked in different northern Italian cities, he found a cordial reception by the rulers of a city that was (and is) connected to water like none other: Venice.

As the Ottoman Empire had conquered Constantinople only five years before and was aggressively breaking into Venice's eastern borders, the Serenissima was in desperate need for skilled military engineers who had hydraulic knowledge also. As a result, in 1502, Leonardo joined the service of Cesare Borgio, who ruled the city as the doge. For the next two years, Leonardo planned and monitored the building of a defensive system on rivers, and even escorted the doge to a campaign in the Romagna. As an interesting side note, Leonardo did not appear to have many moral qualms about also working for the "other side"—an attitude he seemed to share with military suppliers of today.

■ **Note** Also in 1502, Leonardo planned a 720-foot bridge as part of an engineering project for Sultan Bajazet II. This bridge would be made completely from wood and was to span the Golden Horn, an inlet at the mouth of the Bosporus. Though it was never built in his time, in 2001 a Norwegian group reproduced it near the capital of Oslo, almost precisely 500 years after his first drawing (Figure 1-6).

Figure 1-6. *The Norwegian version of Leonardo's bridge project on the Golden Horn*

Leonardo decided to leave the Venetian service after two years and return to Florence. He changed his employer but not his profession. The Florentine Republic engaged him both as a military advisor as well as a hydraulic engineer. Again, both occupations were not completely separate, as one of his first projects was the intended diversion of the Arno River near Florence's old enemy, the city of Pisa, in order to disconnect it from its water supply. Other projects also dealt with the Arno, but were of a more civil nature, such as the plan to extend the navigability of the river and reinforce the embankment near Florence to prevent floods. For that, Leonardo developed some of his largest machines, huge structures intended for use in canal building. It was also in these Florentine years between 1504 and 1508 when Leonardo painted the *Mona Lisa*.

The Aerial Screw and the Flying Machine

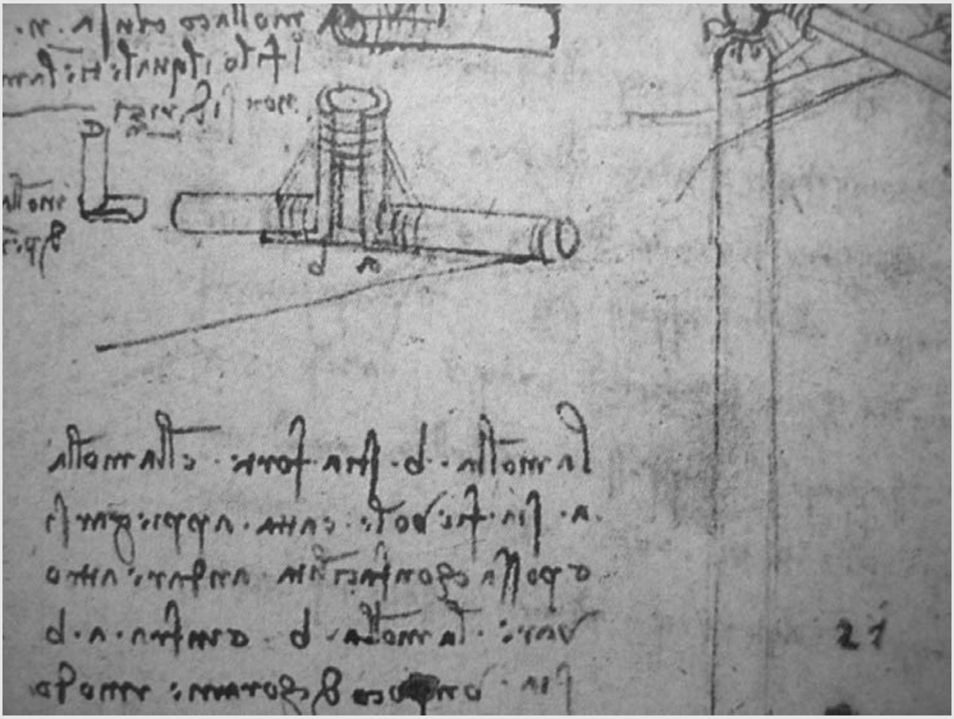
The beginning of the 16th century saw the maturing of Leonardo in an area in which he never presented any of his designs to a paying customer. No doubt this was due to their highly advanced and principally theoretical nature, for the matter in question was no less than the ability of human beings to fly.

OBSCURE MANUSCRIPTS

In spite of their advanced nature (or due to it), Leonardo's mechanical achievements did not contribute to the development of science and technology and did not influence technological progress in the early phase of modern history. His drawings were either obscure to his contemporaries and their offspring or totally unknown and remained so for 300 years. But in the 19th century, engineers were able to appreciate Leonardo's grasp of the mechanical.

More than 5,000 pages of his manuscripts are still available today. Apart from some superficial mentions of Leonardo and his works in some almanacs in the 16th century, these drawings are the only sources of his scientific research that have survived as far as we know.

Leonardo did not publish or otherwise distribute the contents of his notebooks. He did not wish for anybody to see or use his manuscripts. Apart from some drawings he produced for presentation to potential clients, his notes were intended for internal use, as some sort of mind maps. He even took up the habit of laying down the (often just fragmentary) textual explanations next to the actual drawings in mirror writing. In other words, he wrote from right to left so the finished text was the mirror image of normal writing, as shown in the illustration; he did so presumably in order to prevent possible business rivals from stealing his ideas.



Furthermore, Leonardo was left-handed, which would have made writing from left to right pretty cumbersome for him. Writing feathers were shaped to be used by "ordinary" right-handed people then. This left-handedness, though, has helped to distinguish manuscripts written by him from similar ones from this period of time.

Due to the worksheet nature of his manuscripts, many of them were reengineered and extended in the course of Leonardo's life, sometimes even with nontechnical content. This is what made his manuscripts obscure and ambiguous to external readers. In modern times, people are apt to attach concepts of today's world to them. For example, some people inaccurately think he invented the helicopter when he drew the aerial screw. We have to be very careful with such misinterpretations, though there are instances where Leonardo's ideas appear to anticipate modern inventions indeed.

Leonardo was fascinated by flight all of his life and had become convinced that a human being could fly by his own muscle power, an idea he was deeply committed to and didn't give up until his death: ".... you will see the human being with big wings created by him, who will lean against the resistance of air, vanquishing it, being able to outplay and to rise above it," he wrote in 1486. In his opinion, the principal issue was to develop enough energy for the lifting mechanism. That belonged to a class of problems that could be solved by engineering: amplifying the power generated by a human's body by mechanical means. Navigability once the person was in the air was apparently not in the focus of his efforts, as there are not any noteworthy steering contraptions found in any of his according designs.

As previously mentioned, Leonardo considered air a substance that is a lightweight relative of water and thus would follow similar mechanical laws. This general idea led him in 1485 to the design of an *aerial screw*, a device that should "screw" itself into the air like a screw into water (Figure 1-7).

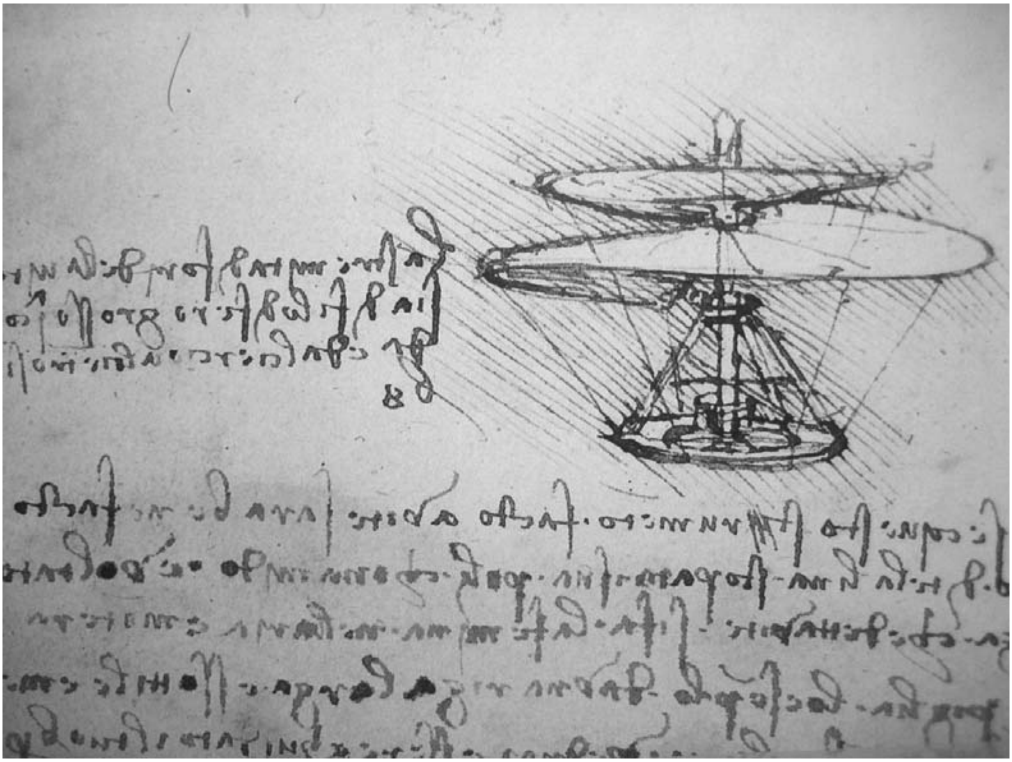


Figure 1-7. *The aerial screw*

In his opinion, the only major problem to solve was the generation of a revolution speed fast enough to make the whole device leave the ground. Obviously, the concept of lift and different levels of pressure on parts moving through the air was unknown to Leonardo, disqualifying the aerial screw as a helicopter; the aerial screw follows a completely different approach.

Leonardo developed many of his ideas for flying contraptions from his anatomical studies. In his opinion, the basic mechanical setup of all living creatures was similar. Hence, these capabilities were not out of the question (e.g., he intensely studied flying fish), in particular when appropriately supported by mechanical means.

Hence his approach toward flying was two-fold. On one hand, he followed the path of creating machines that should amplify man's power as far as possible. One or more pilots were meant to stand upright, sometimes even being required to move their heads and legs in addition to their arms to achieve maximum exploit of the body's muscles. On the other hand, he tried to mimic the mode of operation of birds, insects, and other flying animals, as in the case of his famous design of the flying machine (Figure 1-8).

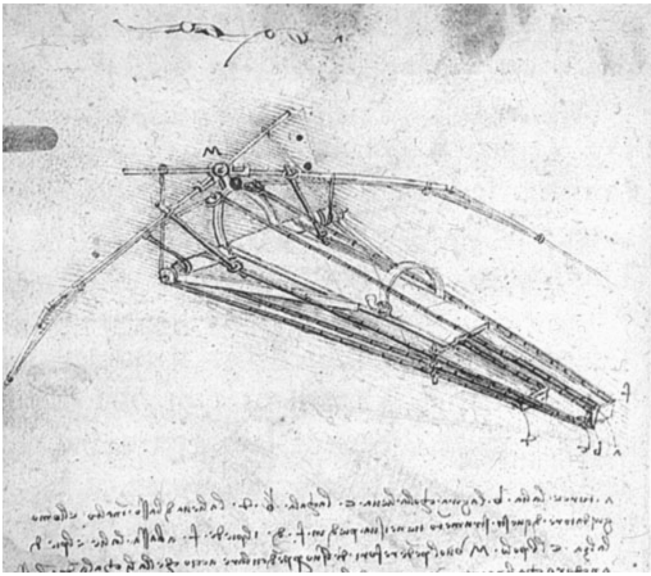
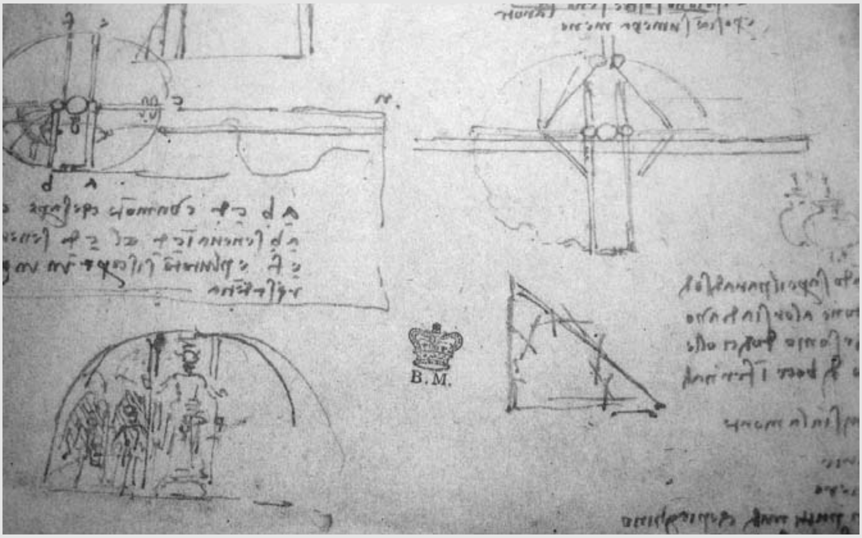


Figure 1-8. *The flying machine*

It was in the first decade of the 16th century that Leonardo wrote a treatise on the flight of birds. Though he tinkered with small models of many of his designs for empirical studies, there is no evidence that any of his flying machines—including the aerial screw and the flying machine—had ever been actually built during his lifetime. However, in our time some of them have been built and tested. His plan for a parachute has been certified to work by a skydiver who used it to jump out of a balloon 9,000 feet above the ground.

LEONARDO'S THEATER STAGE SET FOR ORPHEUS

Leonardo designed an ingenious theater stage set for the popular myth of Orpheus, shown in the following figure. It comprised two hemispheres that could be modeled and painted according to artistic need. They could be opened, closed, and rotated. Hence, with a dramatic theatrical effect, the underworld scene could be brought to the spectators' view by a circular and opening movement, with Pluto emerging on a platform from below accompanied by devils and furies.



It might seem surprising for an engineer to be involved in the theater. However, when considering that Leonardo held the position of director of parades and festivities during his first years in Milan, and that the fine arts and mechanical gadgets played an important part in the Renaissance, Leonardo's activities in that area do not appear that far-fetched. As a matter of fact, it was his capability as a musician that gave the impact for his initial visit to Milan in 1481. Having built a silver lyre in the shape of a horse's head, he presented it to Duke Lorenzo di Medici (nicknamed "Il Magnifico"), the ruler of Florence. The duke, who was given more to diplomacy and good relations with his neighbor cities than to war, considered the beautiful lyre an ideal gift of peace for the authorities of Milan. The duke felt that young Leonardo, who could not only play the lyre very well, but was considered by his contemporaries to be exceptionally talented, handsome, and charming, was ideally suited for the diplomatic mission of delivering the lyre to Ludovico Sforza. Leonardo not only delivered the splendid lyre to Ludovico but also played it in a musician's competition and, according to his biographer Vasari, "played the (horse-shaped) lyre better than any other musicians at Ludovico's court."

Leonardo designed a lot of machines intended for use in performances and already had acquired some reputation as a stage engineer during his first sojourn in Milan. For the Milanese paradise feast he created a set of revolving hemispheres populated with actors impersonating the planets.

Yet, it likely was primarily not that part of his curriculum that induced the new rulers of Milan, the French, to offer him a position as *peintre et ingenieur ordinaire*. As a means of strengthening their position, the French were in need of skilled military engineers, and Leonardo still had an according reputation in the city. Eventually, in 1508, he accepted the offer and moved to Milan again. Here he not only turned to designing and building fortresses but again became concerned with hydraulic projects, this time with sluices, for a possible connection between Milan and Lake Como in the Alps. It was also during these years that he created the theater stage set for Orpheus.

Note In Vasari's biography of Leonardo, he said "[T]he greatest of all Andrea's pupils was Leonardo da Vinci, in whom, besides a beauty of person never sufficiently admired and a wonderful grace in all his actions, there was such a power of intellect that whatever he turned his mind to he made himself master of with ease." Because there is no known portrait of Leonardo in his youth, the only hint of how the great man may have looked is in two supposed self-portraits in his later years. One of these is shown in Figure 1-9.

Figure 1-9. *Supposed self-portrait of Leonardo*

The LEGO MINDSTORMS NXT

Now that you are acquainted with Leonardo and his life, let's take a look at the other topic this book deals with: LEGO MINDSTORMS NXT. In this section you will become familiar with the components that make up the new NXT, bridging Leonardo's world and applying this knowledge to his mechanical designs and reviving them with modern means.

In 1998, LEGO released the first generation of its MINDSTORMS line, the RCX: kits consisting of electric motors, sensors, LEGO bricks, and LEGO TECHNIC pieces grouped around a central controlling unit. Along with a bunch of extension kits, it developed into the most successful product in the company's history. Eight years later its successor, the LEGO MINDSTORMS NXT, finally saw the light of day, first in the United States in August 2006, and two months later in Europe.

The NXT ships in two versions:

- The retail version with 577 parts.
- The education base set with only 431 parts, but with a rechargeable battery and charger. It lacks the retail version's programming software, which is sold separately under different licenses for schools.