LEONARDIAN FLUID MECHANICS

IN THE CODEX ATLANTICUS

X-XII

ENZO MACAGNO

IIHR Monograph No. 116
Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa 52242-1585

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and
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Laboratory Methodology

Beginning at Iowa in the early sixties, the laboratory methodology for the objective study of Leonardo's reported observations and experiments was gradually developed along more than three decades and is still in use. Long periods were spent in fluid mechanics and hydraulics laboratories in the USA and Europe (Iowa Institute of Hydraulic Research, College of Engineering Iowa City, Institut für Hydromechanik Karlsruhe, Laboratoire de Mécanique des Fluides Paris-Orsay, and others). Some illustrations of such a methodology are interspersed in this monograph.
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LEONARDIAN FLUID MECHANICS
IN THE CODEX ATLANTICUS

INTRODUCTION

This is the seventeenth monograph I have written on Leonardian Fluid Mechanics, and the sixth that deals with the Codex Atlanticus (See IIHR Monographs 100, 105, 107, 110, 115). With this monograph my analysis of the Codex Atlanticus is entirely published. It was in fact basically completed some years ago, but for different reasons, the most important being the need and the desire to do work on the synthesis aspects of this project, publication was delayed by the time consuming labor of completing by my own hand the many drawings included.

Any reader with the six volumes at hand will have abundant introductory comments distributed in the first five volumes of the subseries on the Codex Atlanticus. For the sixth volume, I have decided to offer, as the core of the introductory material, a synopsis of all those passages in this Codex in which either experiments or experimental situations are described or referred to. Of course, each of the entries, in a survey like this, should be re-examined in the near future under several criteria. One of them, should be the careful placing of the entry in the context of the other extant Leonardian manuscripts. I have had this aspect in mind while preparing Table I, but only in so far as my memory has helped me to make some occasional reference. Another criterion should be a classification of the entries in categories according to its nature (observation in nature or laboratory, real or thought experiment, question proposed for further study, etc.), associated conception and study (amount of design and work that appears to have been done, instruments used if any, discussion of results, etc.). I have indicated references to work I have already done regarding some of the experiments listed in Table I. This has included in most cases, the use of the Laboratory Methodology I started developing more than three decades ago to help me in the interpretation of Leonardo's notes and drawings. I hope that a visual idea of such work is conveyed by the photographs of some of my experiments which were included in previous monographs and are interspersed in this one.
THE CODEX ATLANTICUS

The Codex Atlanticus, which in fact is not a codex, consists of a collection of well over one thousand sheets put together by the painter Pompeo Leoni at the end of the sixteenth century. According to Professor Augusto Marinoni [1954, 1975], Leoni came into possession of most of the notebooks and papers left by Leonardo da Vinci to Francesco Melzi. Marinoni estimates that initially there were about fifty notebooks and nearly 2000 loose sheets. He does not believe (as Pedretti does) that Leoni destroyed or damaged notebooks to prepare his album, and mentions a study by André Corbeau [1968] in support of his opinion, based on the fact that in the sheets there are no traces of having ever been sewn into a notebook. Marinoni grants, however, that Pompeo Leoni used liberally the scissors and the knife in his separation of notes and drawings referring to artistic and anatomical subjects from those on technological and scientific matters. Leoni appears to have attempted to put into some logical order the sheets and their fragments, but it is obvious to anybody who examines the codex that he was rather unsuccessful, as illustrated in part by Marinoni in his discussion of folios 169, 173 and 177. Leoni did also some damage through his mounting of sheets on inappropriate windows cut in the blank pages of the original atlas. None the less, I think we must still be thankful to Pompeo Leoni, because he helped in preserving hundred of Leonardo's notes for posterity.

In between 1894 and 1904, thanks to the editorial effort of Giovanni Piumati, Ulrico Hoepli of Milano achieved the first publication of the Codex, which in several aspects is still an excellent work. Work for the second printing started in 1962, when the Codex was transferred from the Ambrosiana Library to the monastery of Grottaferrata to be restored with funds provided by the Italian government. The restoration was accomplished under the direction of Father Giosafat Kurilo. According to Marinoni, the old volume, or album, is now at the Ambrosiana: "come spoglia di una larva mutata in un essere più splendido".

Professor Carlo Pedretti is much more critical of the work done in this restoration, which was completed by 1970. I consider that I must mention these aspects, as well as others of scientific interest, because there is always a great danger of inflicting serious damage when - perhaps with the best intentions -- somebody introduces changes in the documents from the past. Pedretti summarizes his opinion in the following sentence: "It is in fact much to be regretted that the 'restoration' has often resulted in serious damage to the originals." In his Catalogue [Pedretti 1978] of the newly restored sheets, he points out for each folio the damage done, and the errors in
mounting the sheets. He also gives the estimated date for each page, information which has been included in these monographs.

The restored Codex Atlanticus has been published by Giunti-Barbera of Firenze [1975-80]. The editor was Prof. Augusto Marinoni of Milano. It consists of twelve large volumes with plates, and twelve smaller volumes with the transcriptions (diplomatic and critical) by Marinoni. There are 1119 folios, of which 998 contain only one of the original sheets, in facsimile of course. The remaining folios contain from two up to thirteen sheets each. The numbering of the folios in the two versions of the Codex Atlanticus is quite different. Marinoni has included in each volume the correspondence between old and new numbers. Such correspondence was also published in the new version of the book by F. Calvi on the manuscripts of Leonardo da Vinci, edited by Marinoni in 1982. I have included this correspondence for each of the folios included in this study of the Leonardian Fluid Mechanics in the Codex Atlanticus, as well as dates estimated by Pedretti.

Over the period of about forty years, reflected in the Codex Atlanticus, Leonardo da Vinci studied many flow and transport phenomena, in nature and in man-made systems, using a methodology in which analogy, paradox, experiments, trial and error, observations, and attempts at mathematization played an essential role. I am convinced that he was more original in his fluid-mechanical studies than in any other field of endeavor, as I have already explained in recent publications [Macagno 1985a,b, 1987a, 1987c].

Leonardian fluid mechanics has only been studied fragmentarily and sporadically in the past, without ever making an attempt at encompassing all of the extant notes and drawings concerning flow and transport phenomena of water, air, fire and granular material, i.e., the four states of matter considered by Leonardo. An important part of Leonardo's notebooks is devoted to the study of fluid and transport flow phenomena as anybody can verify by a perusal of such documents. The Codex Atlanticus contains hundreds of notes concerning fluid mechanics and its applications. It seems, however, that only very few students of Leonardo's work have fully realized, or realize now, the importance of his studies of fluid flow and transport phenomena. The reason may be that one does not perceive certain things unless one has reached a certain level of scientific knowledge and technical experience. There is also, to be taken into account, the effect of a general education influenced by either a statical view of the world or a kinetical one.
ORGANIZATION OF THIS VOLUME

In this monograph, the reader will find a double page arrangement wherever drawings (based on those of Leonardo) have been included to illustrate the passages transcribed from the Codex Atlanticus. When such drawings did not exist or were unnecessary, illustrations of the laboratory method have been used to throw light on other aspects. The page on the left-hand side contains my version in English of such passages, together with my indication of words or sentences that caused me some problems. The words in question are underlined, and the corresponding words in Italian (or more precisely, in Leonardesque) are given. On the right-hand side page there is a succinct "map" of the corresponding page in the Codex, showing the approximate location of the drawings. For such drawings, I have drawn the sketches myself, because I want to give my own interpretation of them as a fluid-mechanicist. My notions about the role and value of images in Leonardo's writings have been summarized recently in a paper [Macagno 1997, Roma].

As explained several times already in my writings, my work is limited to the notes and drawings concerning flow and transport phenomena and related topics (like geometry, kinematics, mechanics, hydraulic engineering, hydrology, etc.). I have adopted an eclectic approach to translation, because each passage needs to be rendered as a unique piece. In some cases, I thought it was better to be as literal as possible, to convey what Leonardo was clearly saying; in other cases, I found that he was not too careful with his writing, but his intention was transparent, and I treated those passages as something to be explained, as a matter of exegetical translation. In addition to this, I have had no hesitation to confess my doubts, whenever they have existed. I know very well that this is not common practice among translators. It is perhaps paradoxical, but it seems that the more one knows about a given field, the more difficult it seems to be sure of what Leonardo says concerning specific topics in such a field. Only generalists seem to make confident translators and not to be disturbed by doubts. In documents as those left by Leonardo there are many ambiguities and many obscure passages. There are notes that are too long, and oftentimes repetitive, while others do not say enough. It is quite probable that some points may remain for ever in doubt. There is still much work to be done before we can offer, for the general public, a truly coherent synthetical version of all the fluid mechanical work of Leonardo. However, in some specialized areas, consistent and plausible views are emerging in my mind, and I would like to refer the reader to the papers I have already published (see Bibliography).
SUMMARY OF EXPERIMENTS IN THE CODEX ATLANTICUS

I have no doubts that Leonardo performed experiments, although only rarely did he care for obtaining any kind of quantitative data. I have described in a synthesis paper, one of such exceptional experiments [Macagno 1991 LHB]. I have also discussed why it was more meaningful and justified for Leonardo - and in his time - to rely preferably on the qualitative kind of experimentation [Macagno 1982]. In many cases, it seems that Leonardo only made a memo to perform the experiment, while in other cases it is quite obvious that we are examining notes and drawings describing a thought experiment. In addition to this, Leonardo included many observations of experimental situations observable in either man-made or in natural conditions. I have chosen to give to Leonardo always the benefit of the doubt when, preparing tables of experiments and experimental situations (see such tables in most of my monographs). I am sure that, in due time, once a critical exhaustive analysis can be carried out, some of the entries will have to be either downgraded or discarded.

I have used for Table I a classification which is based in modern notions. The table is influenced to a certain extent by my work on Libro dell'Acqua [Macagno 1997, Milano]. The topics included in Table I are listed below, together with the number of entries for each, as well as the number of folios in which each kind of experiment was found.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Entries</th>
<th>Folios</th>
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<tr>
<td>1. Physical Properties</td>
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<td>2. Kinematics</td>
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<td>6. Orifice and duct flow</td>
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<td>19</td>
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<td>8</td>
</tr>
<tr>
<td>8. Flow around bodies</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>9. Mass transport</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>10. Momentum transport</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>11. Energy</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12. Thermal flows</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>13. Fluvial hydraulics</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>14. Maritime hydraulics</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Only a few of the experiments, or experimental situations, summarized in Table I are not found, in one form or another, in at least another of the extant documents left by Leonardo. The point may be perhaps best illustrated by mentioning what would have been great losses if we would not possess the Codex Atlanticus as part of Leonardo’s heritage. In Kinematics, entry 7, on Lagrangian description of a flow. In the section on Orifice and Duct Flow, the remarkable experiment on flow of granular material described in Entry 3. In the section on Thermal Flows, the studies of flow in flames, summarized in Entry 3. In the section on Fluvial Hydraulics, Entry 3 shows a particular formation of sediments on the bed of a water stream not to be found in any other Leonardian document. This does not mean that we could do without the other entries, only that for them there is some information in the other notebooks which is enough to, at least, know the essence of the question considered in each entry.

SCIENTIFIC ANALOGIES

After completing my first survey of the Codex Atlanticus, I wrote a paper on analogical thinking as part of the methodology used by Leonardo da Vinci in his technico-scientific studies [Macagno 1986 Brescia]. I am including in this monograph a copy of the multichannel tabulation I prepared for that paper (Table II). I refer the reader to my paper for a really profitable use of Table II. I will summarize here only a few basic thoughts on the way Leonardo used analogies because it is important not to let believe that he used them in a philosophico-literary way, neither did he proceed in the routine way analogies are used by some researchers of our times in their simulations. His was a really creative and critical way of taking advantage of the many analogies that came to his mind and that he considered in detail.

I think that the best way to describe what analogy meant to Leonardo, since he did not define the notion neither did he coined a term for it, is to give (following Bertrand Russell’s approach) an ostensible definition. This is done by presenting the object corresponding to a word, instead of a verbal expression [Russell 1946]. Here is the enunciation of one of the analogies in the Codex Atlanticus:

*Quando tira vento spiana la rena e vedi in che modo essa crea le sue onde e nota quanto essa si muove più tarda che 'vento. E il simile fa dell’acqua e nota le differentie ch e dall’acqua alla rena.* (CA 105aV).
I have found that of all the authors I consulted because of their writings on analogies, J. M. Keynes, in his book on probability, came closest to the notion one gets from a careful study of scientific analogies in Leonardo's notebooks. Keynes defined analogy in terms of propositional functions and introduced the notions of positive and negative components of the scientific analogy. The positive analogy is constituted by the set of propositional functions satisfied by the two objects for which the analogy is introduced. The negative analogy is the set of propositional functions such that each is satisfied by one and not by the other of the objects. Of course, Leonardo rather than writing in general about analogies, created them, studied them, did experiments to clarify them, precisely with the intention of seeing "le differentie". The more differences are discovered, the less valid and worth of treasuring becomes the analogy that may have seduced our mind at the beginning. It is important to recognize that analogical thinking should be handled in different ways in different fields; in zoology, for instance, one should proceed quite differently than in astronomy. In all fields, with perhaps the only exception of poetry, analogies are to be created, used efficiently, and then discarded.

FUTURE WORK

Analysis and Synthesis

With this monograph, my analysis of the Codex Atlanticus is completed (See IIHR Monographs No. 100, 105, 107, 110, 115, in addition to the present monograph, No. 116). I have also completed such kind of study for the manuscripts kept at the Institut de France, although some of them still await publication. This delay is mainly due to the time-consuming preparation of drawings which cannot be trusted to other hands, since nobody else would not know what to draw and how to draw it.

The Codices Madrid, Leicester, Forster and Arundel have already been the object of critico-analytical studies, although not as extensively as those for the Institut de France's manuscripts. Anyway, for all of them the essential flow questions have been identified and commented from the viewpoint of modern fluid mechanics and hydraulics. Among thing to be achieved it remains the complete analysis of a few other documents which have much less fluid mechanical content; however they are not of negligible importance as shown by the detailed surveys of them. I have already done.
Libro dell'Acqua

An important project I have undertaken as part of the synthesis of Leonardian fluid mechanics is the composition of the *Libro dell’Acqua*, as outlined by Leonardo on folio 15 of the Codex Leicester:

1. Dell acque in se
2. Dell mare
3. Delle uene
4. De fiumj
5. Delle nature de fondi
6. Delli obietti
7. Delle giare
8. Delle superficie dell acque
9. Delle cose che in quel son mosse
10. De ripari de fiumj
11. Delli condottj
12. De canalj
13. Delli strumenti volti dall acque
14. Del far montare lacque
15 Dalle cose consumate dall lacqua

One should not make the mistake (which some have made) of believing that the Codex Leicester only needs to be put in order to satisfy the above outline. About as much material from other notebooks should be used to really assemble the *Libro dell’Acqua*. Some of these fifteen sections or chapters would be reduced to a few lines and a few drawings if only material from the Codex Leicester were used. In other words, material essential for the *Libro dell’Acqua* should come from almost all of the extant manuscripts of Leonardo.

I have been working for several years already on this a project, and have recently published a paper [Macagno 1997 Roma ] in which there is a full description of the aims as well as of the state of the project at this time.

As always, I continue to harbor hopes of attracting collaborators for the work of synthesis, of Leonardo's fluid mechanics and hydraulics, particularly in some areas which are less known to me than those of general fluid mechanics and engineering hydraulics. Specially important is to find scholars interested in co-operating in the synthesis of fluvial and maritime hydraulics, flow machines, and some areas of physics in the writings of Leonardo.. Those areas are particularly important for the *Libro dell’Acqua*
ACKNOWLEDGMENTS

My work on the notebooks of Leonardo started soon after I left Argentina, my native country, to become a member of the Iowa Institute of Hydraulic Research (IIHR). For a long time, I devoted my free time and, in many cases my own funds, to the study of Leonardo's particular form of Italian and to the gathering of documentation containing reproductions of his drawings and notes. I received valuable advice from Carlo Maccagni, Giulio de Marchi, and Nando de Toni in the sixties and seventies. In the early sixties, I started developing the laboratory methodology at the IIHR first, and later at the Transport Phenomena Laboratory, which I developed at the College of Engineering of the University of Iowa. In 1974, I began my systematic study of the facsimiles available in Germany, where I was for a year with a Humboldt award at the University of Karlsruhe. Since then, until 1985, I enjoyed always support from German sponsors during the summers I spent at the Institut für Hydromechanik in Karlsruhe. Most of my experiments to gain insight in Leonardian Fluid Mechanics were performed at the excellent laboratory of fluid mechanics of the University of Karlsruhe. For that, and for all the financial and moral support and encouragement I received in Germany during fifteen years, I am forever grateful.

In the 1980's my research work on Leonardian Fluid Mechanics in the notebooks of Leonardo received financial support through a joint grant from the National Science Foundation and the National Endowment for the Humanities of USA; some remnant of their funding is now being used to print this monograph. I am also grateful for a Fulbright Award for the academic year 1986-87, during which I was able to work with Professor Augusto Marinoni at the Biblioteca d'Arte located at the Castello Sforzesco in the City of Milano, in Italy. The staff of that library was extremely kind and helpful. I am greatly indebted to Professor Marinoni of the Commissione Vinciana of Italy for his valuable advice and help, always granted with both great generosity and efficiency. I am also grateful to the Politecnico di Milano, in which Istituto di Idraulica I was given a spacious office and generous secretarial help, as well as free access to their computer systems.

Many persons have generously helped me by agreeing to discuss different aspects of my work, or by lending a hand in libraries, laboratories and class rooms, or by kindly and efficiently answering my letters full of questions. In this respect, I extend my gratitude especially to Professors A. Marinoni, V. Vanoni, R. Caplan, J. Andrews, J. Odgaard, and R. Ettema. Many of my students helped me unknowingly by answering quizzes tailored to discover their primitive
notions or their reactions to puzzling questions that were considered by Leonardo. They also performed some experiments, in their laboratory classes, which were in some way repetitions of those of Leonardo.

My wife, my loyal friend of fifty-six years, has always helped me in all possible ways, not the least being her constructive criticism blended with an unshakable faith in this work. She has become recently co-author, and independent author of publications on Leonardian geometry and kinematics.

I think that one negative frustrating aspect should not be left unmentioned among so many positive acknowledgments. Unfortunately, some pressure has come recently from the bureaucratic sector. To me, it is a duty to denounce such actions. There are people, sometimes, who seem to believe that publications should come out "as soon as possible", on a certain schedule determined by their book-keeper's minds. I must say that I have always resisted all kinds of pressure, and given to the presses my work only when I found it satisfactorily ready, not before. Thus, having started my study of Leonardian Fluid Mechanics in the early 1960's, I only published my first paper in 1982. I believe it is an inalienable right as well as an irrenounceable duty, for any author, to publish when he believes that the work is ready, and not before.

Iowa Institute of Hydraulic Research
January of 1998
BIBLIOGRAPHY


Arredi refers here to a kind of anthological work which should not be called a treatise. It was printed for the first time in 1826 in Bologna as part of Raccolta d'autori italiani che trattano del moto dell'acqua. Almost hundred years later it was published as a separate volume. [Carusi and Favaro 1923].


Physics books of a certain period contain information not known to authors of more recent books. The same is true in the case of the treatise on hydraulics by Spataro included in this bibliography.


DIJKSTERHUIS, E.J. 1957. Archimedes. The Humanities Press, New York. (There is a paperback printing by Princeton University, 1987.)

Excellent example of modern adequate methodology. Dijksterhuis was a professor of History of Mathematics and Natural Sciences at the University of Utrecht. See, on p. 379, the statement that our concept of pressure was alien to Archimedes. See also comments by W. R. Knorr at the end of the book. (p. 419)


Together with Arredi's, Giacomelli's approach to Leonardo's work is always a model for my work. There is nothing that can replace the direct reading of the documentation instead of depending on translations.


See "Leonardo's Method of Working out Compositions", pp. 58-63. The plates 93 & 94 show the verso and recto of Study for the Virgin with St. Anne. Anybody who wants to understand Leonardo's trial-and-error methodology would do well to study carefully these two plates. In my opinion, this is a beautiful example of how this artist was armed with methods of universal application, enabling him to make progress in his scientific investigations.


This study is excellent in some respects, but the author (as many others) completely overlooked the mechanics of fluids and the transport phenomena, as if they were not mechanics! Because of the time at which this work was done, it could not possibly include the Codices Madrid, so important for the questions of general mechanics. Hart seems to have been unaware of the investigations of Giacomelli concerning aeronautics. Very valuable, in this book, is the Foreword by E. A. Moody. Moody made some valid critical remarks but not that of Hart overlooking so much of the studies of kinematics and mechanics by Leonardo.


Keynes offers a keen analysis of scientific analogy which matches very well the way in which Leonardo da Vinci worked with analogies in his studies of fluid flow and transport phenomena.


This book is one of the most interesting essays I know about the exploration of creativity in the mathematical mind. Hadamard gives credit to Henri Poincaré for the inspiration to do his work. (See Appendices I and II for an interesting inquiry concerning the working methods of scientists, and Albert Einstein answer to it.)


This is the second doctoral thesis defended by the author at the University of Grenoble in 1953. It contains several flow visualizations of the flow of granular materials.
See, on page A-14, flow visualizations in channel flow with the typical diagonal waves that one can find, e.g., in the Ms F. This is important because such waves do not exist in conduit flow, and therefore no hydraulician would because of that confuse one flow with the other. Of course, confusion is possible for other students of Leonardo.


These Internal Reports contain descriptions of the work at the fluids laboratory of the Karlsruhe Hydromechanics Institute, most of which has been included in publications listed below.


A number of applications of the laboratory methodology to the study of Leonardo's notebooks are illustrated in this contribution. Some of the experiments are from the Codex Atlanticus.


In this contribution, several remarkable experiments by Leonardo are studied, including some of the paradoxical situations which were probably used in the way of reductio ad absurdum.


In this paper, a number of experiments are reported which were performed as an application of the laboratory methodology in the analysis of documents, developed by the author from 1965 to 1980, at the Iowa Institute of Hydraulic Research first, and then at the Institut für Hydromechanik Universität Karlsruhe.

MACAGNO, E., 1986a. What has not been explored in the Codex Hammer. Invited Lecture, Symposium on Leonardo in a new Perspective. Spencer Museum of Art, The University of Kansas, Lawrence, March 22, 1986. (A revised version has been published in 1988 as a volume of the series Leonardian Fluid Mechanics, IIHR Monograph No. 101, by The University of Iowa.)


MACAGNO, E. 1987b. La noción de presión en la mecánica de fluidos Vinciana. Raccolta Vinciana. Fascicolo XXII, Milano, Castello Sforzesco

This paper is mainly about the paradox that Leonardo understood pressure better than hydrostatic force, but contains also considerations about the use by Leonardo of paradoxes in his study of hydrostatics.


This monograph contains descriptions of some applications of the laboratory methodology in the study of the notes of Leonardo on flow and transport phenomena.


MACAGNO, E. 1988c. Leonardian Fluid Mechanics in the Manuscript H. IIHR Monograph No. 103. The University of Iowa, Iowa City, IA, USA.

MACAGNO, E. 1988d. Leonardian Fluid Mechanics in the Manuscript C. IIHR Monograph No. 104. The University of Iowa, Iowa City, IA, USA.

MACAGNO, E. 1989a. Leonardian Fluid mechanics in the Codex Atlanticus. I-III. IIHR Monograph No. 105. The University of Iowa, Iowa City, IA, USA.

MACAGNO, E. 1989b. Unexplored Flow Studies in the Codex Arundel 263. IIHR Monograph No. 106. The University of Iowa, Iowa City, IA, USA.

MACAGNO, E. 1989c. Leonardian Fluid mechanics in the Codex Atlanticus. IV-V. IIHR Monograph No. 107. The University of Iowa, Iowa City, IA, USA.

MACAGNO, E. 1989d. Leonardian Fluid mechanics in the Manuscript L IIHR Monograph No. 108. The University of Iowa, Iowa City, IA, USA.

MACAGNO, E. 1989e. Leonardian Fluid mechanics in the Manuscript M IIHR Monograph No. 109. The University of Iowa, Iowa City, IA, USA.

MACAGNO, E. 1989f. Leonardian Fluid mechanics in the Codex Atlanticus. VI-VII. IIHR Monograph No. 110. The University of Iowa, Iowa City, IA, USA.
The priority in developing the two main views of fluid flow has been debated (H. Lamb and C. Truesdell) because it was developed during the same years by both Euler and Lagrange, but indeed, both descriptions were already used by Leonardo. This, of course, he did with simpler transformation-geometry diagrams.

Most analysts and anthologists of Leonardo's work have either overlooked or misunderstood the drawings in the Codex Leicester which are mostly on flow and transport phenomena.
The first part is on Leonardo da Vinci's kinematics; the second part describes the inception of modern kinematics in France. The term kinematics was introduced by Ampère in his famous essay on the old and new sciences.


Systematic use of the Math Lab methodology can be found in this contribution. The section that should be most useful in connection with Leonardian Fluid Mechanics is that devoted to deformation of geometrical figures and bodies.

MACAGNO, M. 1988. Geometry in Motion. Monograph Department of Mathematics, University of Iowa, Iowa City, IA.


I believe that if one is familiar with the Prandtlian approach to fluid flow phenomena, one should have a view that is very adequate for the study of the Leonardian science of flow and transport phenomena. As fluidodynamicists, da Vinci and Prandtl could not have been more different, however there are important lines of thinking, and even of intuitive powers, in common in these two men, which would be very interesting to study in depth. To a certain extent, I consider that Sir Geoffrey Taylor offers also a similar possibility. [See Taylor 1958]. In the field of Hydraulics, I think that Hunter Rouse is an author, and a man, worth studying to better understand Leonardian hydraulics.[See Rouse 1971].

ROUSE, H. 1971. Selected Writings. Dover. (See also his books on fluid mechanics.)


Similar comments as those for Prandtl 1961 are applicable to the work of G. I. Taylor.

<table>
<thead>
<tr>
<th></th>
<th>Physical Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Measurement of humidity in atmospheric air by means of a balance, one side of which is loaded with an object that is hygroscopic.</td>
<td>30V</td>
</tr>
<tr>
<td>2</td>
<td>Demonstration of the effect of water surface tension on the shape of the air-water interface. Instead of using coins on can easily reproduce this effect with a glass of water and a sugar dispenser. &quot;After a glass is filled to capacity with water, put in it coins up to 3 'lire'; but you must drop them one by one and edgewise.&quot; (CA 958R).</td>
<td>40R</td>
</tr>
<tr>
<td>3</td>
<td>Some optical properties of hemi-spherical bubbles floating on a layer of water are studied.</td>
<td>205R</td>
</tr>
<tr>
<td>4</td>
<td>Experiment to show that as one heats water that is turbid with mud it becomes clear.</td>
<td>207V</td>
</tr>
<tr>
<td>5</td>
<td>Leonardo considered the water as an incompressible fluid. &quot;This can be proven by putting water in a container of narrow mouth; unless one used some ingienjo one cannot put more [water] than the natural capacity of such a container&quot;. (CA 299R). But if one can use a machine to put more water in the container one must think that, probably, the water is compressible and the container, expandable.</td>
<td>299R</td>
</tr>
</tbody>
</table>

* Drawings, in this table, are all by the author. When they are based in those of Leonardo, they are reduced to their essentials. In a few of the drawings, arrows, or other symbols, and brief notation has been added. EM indicates auxiliary drawings introduced by the author.
### Physical Properties

**303V**

At first I thought D8 and D9 were related to paradoxes presented by Leonardo in the Codex Leicester (Macagno 1997, Milano), but Leonardo's note for these drawings refers to this experiment as one for demonstration of rarefaction of water, which he considered as contraposed to incompressibility.

<table>
<thead>
<tr>
<th>303V</th>
<th>D9</th>
<th>D8</th>
</tr>
</thead>
</table>

**646R**

The interface air-water can reflect light both on the air side and in the water side. Leonardo has referred more than once to the reflection of a source of light on the wavy surface of water. Examination of the Codex Leicester shows that Leonardo meant the subject of optical properties of water to be included in his *Libro dell' acqua* [See Macagno 1997, Milano].

<table>
<thead>
<tr>
<th>646R</th>
<th>D9</th>
</tr>
</thead>
</table>

**EM**

"Painters are mistaken in many cases when they depict water because they make the water see what the man sees; but the water sees an object from one side and man sees it from another. Many times it happens that the painter sees something from above while the water sees it from below. Thus, one object is seen from the front and the back, from above and from below, because the water shows the image of the object in one way and the eye sees it in another (way)."

<table>
<thead>
<tr>
<th>EM</th>
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</table>

**1015R**

"Why the water drop does not fall vertically under the angle $a$ as under $n$? And why when the water increases, it flows farther and farther from its angle?"

<table>
<thead>
<tr>
<th>1015R</th>
<th></th>
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</table>

Do not be misled by the manner in which the family of solutions is displayed.
### Kinematics

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kinematics</td>
<td>In 82R, the deformation of several bodies is studied. For cylinders subjected to different deformations, marks are made on the surface of the cylinder in order to visualize the deformation attained after is given different shapes. For the study of deformations in the notebooks of Leonardo, see M. Macagno 1987, 1992, 1995.</td>
</tr>
<tr>
<td>2</td>
<td>Kinematics</td>
<td>Studies of the shapes of different vortices produced in air and in water. For the role of vortices in the book on water Leonardo wanted to write, see Macagno M. 1007, Milano.</td>
</tr>
<tr>
<td>3</td>
<td>Kinematics</td>
<td>Technique for the visualization of air flow by the use of smoke.</td>
</tr>
<tr>
<td>4</td>
<td>Kinematics</td>
<td>Use of the retention of images on the retina to visualize the motion of rapid moving objects. Leonardo's examples are a whirling stone and a rain drop.</td>
</tr>
<tr>
<td>5</td>
<td>Kinematics</td>
<td>Leonardo used several techniques to produce flow visualizations. A glass-walled tank is used to be able to observe the flow of water towards an orifice. The visualization is accomplished by means of seeds suspended in the water as tracers. (CA 219R) The addition of ink to water is mentioned in CA 349R.</td>
</tr>
<tr>
<td>Page</td>
<td>Section</td>
<td>Text</td>
</tr>
<tr>
<td>------</td>
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</tr>
<tr>
<td>6</td>
<td>Kinematics</td>
<td>Flow visualization using wine as a dye. It seems that, in this experiment, Leonardo did not realize the effects of rotation on flow patterns. (See Macagno 1982 for a critical analysis of this point).</td>
</tr>
<tr>
<td>7</td>
<td>Kinematics</td>
<td>In CA 407R D4, and more clearly in D6, Leonardo shows his view of a jet or a nappe from what we call now a Lagrangian point of view. (See Macagno 1992, Rac. Vin.); This is one of the instances in which we see what can be called an analysis of experimental results by Leonardo (See Macagno, 1991 LHB, Paris, for other cases of analysis of experimental results by Leonardo.)</td>
</tr>
<tr>
<td>8</td>
<td>Kinematics</td>
<td>Another example of Lagrangian point of view as anticipated by Leonardo is given by what may be termed as Math Lab experiment in which pieces of paper or cardboard can be displaced to illustrate conservation of area or volume.</td>
</tr>
</tbody>
</table>
| 9    | Kinematics | CA 1007R must be studied together with other passages (especially Ms A 57) if one is to understand Leonardo's grasping of conservation of volume - as an excellent approximation - in the flow of liquids. [See Macagno 1992, Rac Vin.] In Ca 1106R, Leonardo appears to apply conservation of volume to a certain air flow. (This is a good approximation in some cases). A more complete sketch can be found in Ms A 57.
## EXPERIMENTS AND EXPERIMENTAL SITUATIONS IN THE CODEX ATLANTICUS

<table>
<thead>
<tr>
<th></th>
<th>Hydrostatics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Leonardo studied the shape of drops of different liquids laying on a solid surface or hanging from it, as well as coalescing drops (compared by him to &quot;calamita&quot;).</td>
<td>205R</td>
</tr>
<tr>
<td>2</td>
<td>Some of the hydrostatics experiments in this folio may be thought experiments. D2 and D3 represent experiments that would use the human body-or part of it-to sense the effects of hydrostatic pressure. (See similar experiments in Codex Madrid I.)</td>
<td>303V</td>
</tr>
<tr>
<td>3</td>
<td>The approach of Leonardo to hydrostatics was such that experiments in which water jets are examined may well belong to hydrostatics because they are used to reveal the pressure in the container. This is an experiment that I used in my courses) Experimental Fluid Mechanics and Undergraduate Fluid Mechanics) because is very revealing and it is insuperably simple.</td>
<td>303V</td>
</tr>
<tr>
<td>4</td>
<td>Experiments with balances and corresponding mirror-image balances under water are illustrated in CA 515V.</td>
<td>515V</td>
</tr>
<tr>
<td>5</td>
<td>The system weight-bellows-fluid is used here to study the pressure generated by means of a manometric tube connected to the fluid reservoir of such a system.</td>
<td>549R</td>
</tr>
</tbody>
</table>

Comparison of densities using a balance and a liquid in a container is the subject discussed in CA 773R.
<table>
<thead>
<tr>
<th>Page</th>
<th>Subject</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Hydrostatics</td>
<td>Placing an inverted bottle or a glass so that it is partially immersed in the water of a vessel created hydrostatic problems that it is not clear Leonardo was able to solve satisfactorily. [See Codex Leicester, and analysis by Macagno 1986, Mon. 101].</td>
</tr>
<tr>
<td>7</td>
<td>Hydrostatics</td>
<td>Leonardo studied experimentally bubbles floating on the surface of stagnant water. As part of his Laboratory Methodology, Macagno studied soap bubbles which were let fall on the surface of stagnant water; they have a short life, and they become hemi-spherical when they do not collapse. [Macagno 1975-85]</td>
</tr>
<tr>
<td>8</td>
<td>Hydrostatics</td>
<td>One advantage of considering hydrostatics from a dynamic point of view is that the problem of relative equilibrium offers no difficulty. This was impossible for Leonardo, and thus the experiment in which the water is higher near the wall of a rotating cylindrical container was much more important and puzzling for Leonardo than it is for us.</td>
</tr>
<tr>
<td>9</td>
<td>Hydrostatics</td>
<td>To Leonardo, even the simplest experiments in communicating vessels were of paramount importance.</td>
</tr>
<tr>
<td>10</td>
<td>Hydrostatics</td>
<td>By means of a balance, the density of clear and turbid waters can be compared.</td>
</tr>
</tbody>
</table>
### Hydrostatics

#### 973R

"If the weight \( m \) be 10000 'libbre' and the orifice \( n \), in the bottom of the vessel \( a \), is contained 100 times in such vessel, the hundredth of such weight will exert a force on such orifice, i.e., 100 'libbre'. And following this same rule, the vessel \( b \) underneath would exert a force on the orifice \( o \) in the amount of one 'libbra'." (CA 973R)

![Diagram](D1)

#### 1016R

"It is shown by experiment that given 2 equal volumes of water and air enclosed in 2 vessels joined together, and placing the air under the water of a pool and the water in the air - the water is then supported by the air".

When I first studied these experiments by Leonardo, I thought that he was concerned with stability of floating bodies; soon I realized that he was performing crucial qualitative experiments, that challenged tenets of old and Medieval physics. (For similar experiments see, e.g., Codex Madrid I/)

![Diagram](D2)

#### 1023V

Leonardo knew a lot about hydrostatics, but he knew it differently from Archimedes and from us. He also had misconceptions we do not have, neither had Archimedes. In spite of having conceived very revealing experiments [Macagno 1982], Leonardo appears to have died with a fundamental misconception about hydrostatic forces in a tank of water. Such a misconception is clearly stated in CA 1023V.

In D8 of 1023V, Leonardo depicted (poorly however) a device to measure the force on the bottom of a tank full of water.

![Diagram](D8)
EXPERIMENTS AND EXPERIMENTAL SITUATIONS IN THE CODEX ATLANTICUS

<table>
<thead>
<tr>
<th></th>
<th>Hydrodynamics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jets with different properties were produced by changing parameters in Leonardo's frequently discussed system weight-bellows-water reservoir. He clearly knew that the height and the rate of flow were dependent on what we call pressure of the fluid. (See remarkable device in Codex Leicester, IIHR Mon. 101) In some cases, the system weight-bellows-fluid is found in the context of a technical application, or as part of a supposedly perpetual-motion device (CA 880R). The experimental situation in CA 882V is analyzed in Macagno 1987, Rac. Vin.</td>
<td>64R 549R</td>
</tr>
<tr>
<td>2</td>
<td>Study of the vortices generated at the interface of two confluent streams. Although Leonardo only slightly scratched the surface in this topic (as in others), it took centuries before the generation of vortices became a fruitful area of study in fluid dynamics.</td>
<td>211R</td>
</tr>
<tr>
<td>3</td>
<td>Water fall at the end of a channel. The question is the correlation between water depth in the channel and rate of flow in the water nappe.</td>
<td>219R</td>
</tr>
<tr>
<td>4</td>
<td>Studies of impinging jets and currents can be found in several of Leonardo's notebooks. CA 465R D2 and CA 796R D2 appear to be instances of such a phenomenon. (See Macagno 1982). Some drawings in CA 1098R are described by Leonardo as those of impinging currents.</td>
<td>465R 796</td>
</tr>
</tbody>
</table>

D1 D2 D4
<table>
<thead>
<tr>
<th>Page</th>
<th>Code Ex.</th>
<th>Topic</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>474aR</td>
<td>Hydrodynamics</td>
<td>Experiments involving circular waves can be found in several notebooks. Regarding CA 474aR D1, Leonardo is concerned with the result of generating three circular waves, one at each vertex of a triangle. A similar problem is considered in Codex Madrid I (see Macagno 1982) and also in CA 536R D. At some distance from the individual sources, the resulting wave system is nearly circular.</td>
</tr>
<tr>
<td>6</td>
<td>526aV</td>
<td>Hydrodynamics</td>
<td>An interesting interpretation of the hydraulic jump at the foot of a chute which is followed by an ascending bottom. Leonardo points out that one should theoretically expect to see the water rushing down, take a turn, and then rush up as it would do in V-shaped conduit (See Codex Madrid I as discussed by Macagno 1982.)</td>
</tr>
<tr>
<td>7</td>
<td>537R</td>
<td>Hydrodynamics</td>
<td>CA 537R D6 is suggestive of an experiment to study the flow of water of one density into water with a somewhat different density.</td>
</tr>
<tr>
<td>8</td>
<td>645R</td>
<td>Hydrodynamics</td>
<td>This passage is about interpretation of observations of jets. If resistance to flow is introduced, rather simple calculations can show us today that a jet coming out horizontally from an orifice will describe a curve that is not parabolic because it must have a vertical asymptote. Any historian of science with this knowledge can understand Leonardo's discussion of D1 in CA 645R.</td>
</tr>
<tr>
<td>9</td>
<td>886V</td>
<td>Hydrodynamics</td>
<td>Studies of flow in pipes whose axis is in the shape of a cylindrical helix. Perhaps, Leonardo's interest is related to Archimedes screw, although helical pipes are included as part of some of his siphons (see e.g. Ca 882V).</td>
</tr>
<tr>
<td>Page</td>
<td>Hydrodynamics</td>
<td>894V</td>
<td></td>
</tr>
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<tr>
<td>10</td>
<td>Vertical descendent jets - presumably in laminar mode of flow - break into string of drops and eventually become unstable.</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Page</th>
<th>Hydrodynamics</th>
<th>979V</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>&quot;Why a (single) percussion on the water makes several waves?&quot; &quot;Each circular wave is reflected toward its origin in that portion which is missing and would complete the greatest circle&quot;. (CA 973V)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Page</th>
<th>Hydrodynamics</th>
<th>980aR</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Studies of breaking waves can be found in several of Leonardo's manuscripts. In CA 980aR Leonardo compares waves breaking in rivers with those breaking on the sea shore. (The latter are studied, e.g., in Codex Madrid I)</td>
<td></td>
</tr>
</tbody>
</table>
### Siphon flow

<table>
<thead>
<tr>
<th>Page</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>165R</td>
<td>In 165R, 218R, and 1069R a siphon is drawn that suggests an explanation for &quot;Tantalus&quot; vase.</td>
</tr>
<tr>
<td>218R</td>
<td>Several different siphons are drawn in these folios in a manner that is highly suggestive of an extensive series of tests. It is rarely possible to be sure that Leonardo's notes correspond in fact to experiments actually carried out by him, but, as a rule, he shows a knowledge which seems very improbable without a number of experiments having actually been performed [See comment by Leonardo for CA 882V D12, and his statement against the possibility of &quot;moto chontinuo:&quot; in CA 886R]. Leonardo's comments in CA 922R about &quot;le mie regole&quot; seem to be a warning against those who promise impossible things (like &quot;moto chontinuo&quot;)</td>
</tr>
<tr>
<td>1069R</td>
<td></td>
</tr>
<tr>
<td>537R</td>
<td>By means of a strip of cloth it is possible to siphon out water from a container. A similar experiment is depicted in the Codex Leicester. (See Macagno 1986, IIHR Mon. 101).</td>
</tr>
<tr>
<td>790R</td>
<td>In 790R D3, Leonardo illustrates a two-phase flow in a siphon in which the flow of water is coexistent with a chain of air bubbles.</td>
</tr>
<tr>
<td>882V</td>
<td>D3 and D4, in CA 882V, are strongly reminiscent of two drawing in the Codex Leicester which I have discussed as paradoxical experiments in several papers [See the last, Macagno 1997, Milano]. The significance of this paradoxical experiment can easily be missed if one fails to use elementary physics [Zeri et al. 1995].</td>
</tr>
<tr>
<td>Experiment</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td><strong>Orifice and duct flow</strong></td>
</tr>
<tr>
<td>42R</td>
<td>In 42R uniform flow of a liquid out of a vessel would provide measurement of time. It is not clear how the constant rate of flow is ensured.</td>
</tr>
<tr>
<td>42V</td>
<td>In 42V a bellow containing air and loaded with lead on top would presumably empty at a uniform rate, thus providing a means of measuring time.</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td><strong>Orifice and duct flow</strong></td>
</tr>
<tr>
<td>218R</td>
<td>Determination of discharge of water through an orifice in a tank as a function of the water head in the tank.</td>
</tr>
<tr>
<td>219R</td>
<td>Study of the shape of orifices and nappes.</td>
</tr>
<tr>
<td>256R</td>
<td>Study of the effect of the location of the orifice in the bottom of the tank.</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><strong>Orifice and duct flow</strong></td>
</tr>
<tr>
<td>303R-V</td>
<td>Experiment to show that water coming out of a triangular conduit does maintain a triangular cross-section. (CA 303R D10)</td>
</tr>
<tr>
<td>398R-V</td>
<td>As a student of my course Experimental Methods in Fluid Mechanics S. Jain performed a similar experiment at the IIHR with an air jet.</td>
</tr>
<tr>
<td>457R</td>
<td>For a circular tube the question considered by Leonardo was the rectilinearity of the jet until the liquid impacted the ground. (D4)</td>
</tr>
<tr>
<td>949V</td>
<td>For this problem, Leonardo also used the analogy liquid flow-granular-material flow. (303V)</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td><strong>Orifice and duct flow</strong></td>
</tr>
<tr>
<td>303R</td>
<td>Leonardo studied the flow of different liquids out of a tank through an orifice. The results, sometimes strange, may be due to either stratification of density or rotation of the fluid. (See Macagno 1982).</td>
</tr>
<tr>
<td>303V</td>
<td>The flow of granular material through an orifice at the bottom of a container was considered by Leonardo as an analogy of the similar flow of liquids. (See 303 D4, 349R D6, and my experiments illustrated on p. ii If IIHR Mon. 107, Macagno 1989.)</td>
</tr>
<tr>
<td></td>
<td>Falling bodies and Projectiles</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>1</td>
<td><strong>185V 1047R</strong>&lt;br&gt;In 185V the falling body is a board which is expected to stay horizontal if released in air in that orientation. If Leonardo actually observed coins dropped in water (see CA 40R) he must have noticed that they tumble down and do not preserve the initial orientation. He reports cards doing something similar.</td>
</tr>
<tr>
<td>2</td>
<td><strong>185V 691R</strong>&lt;br&gt;In 185V, Leonardo discussed the fall of a number of elongated bodies of different shapes. In 691R, proposes the study of a falling card. (Let us hope somebody does not make Leonardo into a precursor of the study of chaos theory). On this page we find what may be considered as proven by a large number of experiments: &quot;And the heavier part of the bodies, after the beginning of their motion, becomes the guide of such body.&quot; It is not difficult to find exception to this rule which seems to be a piece of Medieval fluid dynamics.</td>
</tr>
<tr>
<td>3</td>
<td><strong>190R 205R 796R</strong>&lt;br&gt;In 190R, Leonardo studied liquid drops falling through air and impacting the water surface in a pool. One drawing of a falling drop is in 205R. Coalescence of falling drops is discussed in CA 796R.</td>
</tr>
<tr>
<td>4</td>
<td><strong>1061V</strong>&lt;br&gt;Observations of snow accumulationns on objects, forming a cover. Such formations are seen as an analogical phenomenon to deposits of sediments upon shapes in the bottom of bodies of water.</td>
</tr>
</tbody>
</table>
## EXPERIMENTS AND EXPERIMENTAL SITUATIONS IN THE CODEX ATLANTICUS

<table>
<thead>
<tr>
<th></th>
<th>Flow around bodies</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>215R</td>
<td></td>
</tr>
<tr>
<td>215R</td>
<td>Comparison of the flow around a body moved through quiescent water and the flow of water around the same body in a fixed position.</td>
<td></td>
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</table>

### Flow around bodies

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<thead>
<tr>
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<th>Flow around bodies</th>
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<tbody>
<tr>
<td>2</td>
<td>460V</td>
<td></td>
</tr>
<tr>
<td>460V</td>
<td>In 460V D1 Leonardo drew several elements of the flow pattern around an elongated body, presumably implanted in a channel. In his notes on folio 460 he discussed flow of water and air, always considering one incompressible and the other compressible. (See application of the Laboratory Methodology in the study of this and similar passages, Macagno 1989m IIHR Mon. 110),</td>
<td></td>
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### Flow around bodies

<table>
<thead>
<tr>
<th></th>
<th>Flow around bodies</th>
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<tbody>
<tr>
<td>3</td>
<td>675R</td>
<td></td>
</tr>
<tr>
<td>675R</td>
<td>A plate hanging like a pendulum can be deflected by the wind and thus serve as a device to measure the wind velocity. A line by Leonardo seems to indicate that this instrument can be used to measure the speed of a ship. This would be in agreement with his notion of equal effects under any relative motion of fluid and object. (Let us hope somebody does not make Leonardo into a relativist just because of this.),</td>
<td></td>
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</tbody>
</table>

### Flow around bodies

<table>
<thead>
<tr>
<th></th>
<th>Flow around bodies</th>
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</tr>
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<tbody>
<tr>
<td>4</td>
<td>781aR</td>
<td></td>
</tr>
<tr>
<td>781aR</td>
<td>In my opinion, the sketches D1 and D2 in CA 781aR are representations of flow around clusters of obstacles.</td>
<td></td>
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</tbody>
</table>

### Flow around bodies

<table>
<thead>
<tr>
<th></th>
<th>Flow around bodies</th>
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<tbody>
<tr>
<td>5</td>
<td>928R</td>
<td></td>
</tr>
<tr>
<td>928R</td>
<td>Orientation of a plate mounted on a balance and exposed to uniform wind first and to non-uniform wind afterwards.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mass Transport</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------------------------------------------</td>
<td>---</td>
</tr>
<tr>
<td>1</td>
<td>Several aspects of transport of sand and other sediments were observed by Leonardo in canals, rivers and the sea. This results generally in some kind of waves at the interface between fluid and solid (granular usually).</td>
<td>865R</td>
</tr>
<tr>
<td>2</td>
<td>&quot;I have a glass of wine and take out half of the wine and replenish the glass. Now the glass is half wine and half water.&quot; Leonardo concludes that even if the process is infinitely repeated, there will always remain some wine in the glass. (See analysis of a similar experiment in Macagno 1995, Rac. Vin.)</td>
<td>585R</td>
</tr>
<tr>
<td>3</td>
<td>A water jet penetrating the nearly stagnant water of a pool is a subject explored by Leonardo in several places. In some cases the focus is on the jet reaching the bottom of the pool and causing erosion, and in other cases, like in CA 943R, the entrainment of air and its ulterior return to the atmosphere is the central aspect.</td>
<td>943R</td>
</tr>
<tr>
<td>4</td>
<td>The erosive power of vortices is described in many passages in Leonardo's notebooks. [See, especially Ms F and Codex Leicester as summarized in Macagno 1995, Rac. Vin.].</td>
<td>1007R</td>
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<td>19R</td>
<td>Momentum Transport</td>
<td>Static measurement by means of a balance of the force applied on a plate by a water nappe.</td>
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<tr>
<td>407R</td>
<td>Momentum Transport</td>
<td>The momentum of combustion gases in a duct can impart rotation to the helicoidally shaped blades of a rotor.</td>
</tr>
<tr>
<td>415R</td>
<td>Momentum Transport</td>
<td>An analogy is behind the two experiments illustrated by D3 and D4 in CA 674R. Leonardo comments: &quot;this is a bello dubbi&quot;. And I immediately thought of the kind of questions of my teacher at the University of La Plata who guided me through two annual courses of Experimental Physics in the late thirties. These experiments are not impossible to perform, but I see them as &quot;gedanken' experiments more than anything else. The fact that Leonardo ends his comments with a question (exactly like those of my teacher): does the balance shows peso or leuita?</td>
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<td>888R</td>
<td>Energy</td>
<td>It is from experiments that we know that there is no machine which would do more work than the input of energy it receives. Therefore, when Leonardo states examines a lifting-water machines, he is doing a valid experiment to disprove a claim of 100% efficiency or higher. He shows some knowledge of conservation of energy and of its dissipation which is surely different from ours but that exists anyway.</td>
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<td>Thermal flows</td>
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<td>1</td>
<td>Leonardo studied several flows induced by differences in temperature in the fluid. The kitchen, and the shop of an artist are two places in which observations of the effects of introducing heat into a liquid is almost unavoidable. Leonardo described in Ms F 34V a flow visualization technique to observe thermal flows in water. [Macagno 1995, Rac, Vin.].</td>
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<td>2</td>
<td>In CA 226V Leonardo summarized his knowledge of the flow patterns induced by a candle placed in a tube open at the top end.</td>
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<td>3</td>
<td>In several folios of the Codex Atlanticus, Leonardo summarizes his observations of the thermo-fluid mechanical phenomena associated with one of the commonest flames, that of a candle. I believe that part of that knowledge was obtained by some kind of shadowgraph technique. For the case in which the flame is confined within a tube see Codex Madrid I [Macagno 1982].</td>
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<td>&quot;Put a (balloon) bottle upside-down in a water bowl, and in the bottom put a burning coal. It will have enough power for its heat to pull up the water and fill such bottle&quot;. See a similar situation in the Codex Leicester and analysis by Macagno 1986, Mon. 101. This experiment may give results dependent on a parameter: the amount of heat transferred, but I still believe that Leonardo interpreted it according to a misconception.</td>
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<td>1</td>
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<td>In 70aR, the distribution of different sediments along river meanders is considered.</td>
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<td>Study of the erosion of a mound of erodible material with water flowing on both sides of it.</td>
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<td>Formation of V-shaped waves in the sedimentary bed of a straight channel when such a bed is made up of non-uniform material.</td>
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<td>4</td>
<td>575V 576bV</td>
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<td>A water jet can not only penetrate the water of a pool, but also reach the bottom and cause a scour hole if the bottom is erodible.</td>
<td>576bV</td>
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<td>5</td>
<td>674R 785bR 910V</td>
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<td>In CA 674R, Leonardo summarizes some field observations about meandering rivers. His drawing illustrate a minor meandering channel inside the large meandering channel.</td>
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<td>Model of the Mediterranean Sea. The plan for such a model contains provisions for modeling the rivers discharging their water in that sea, for the sand at the bottom, etc. The sketch seems rather poor to me and I cannot recognize in it a map of the Mediterranean sea.</td>
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### TABLE II

Tabular survey of analogies in the Codex Atlanticus

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| FOLIO  | CA     | FIRE | LIQUID | SOLID | GRANULAR | FLEXIBLE | GRAVITY | MAGNETISM | DENSITY | COMPRESSIBILITY | SURFACE TENSION | FLOW | CURRENTS | CIRCULATION | 3-3 PHASES | TURBULENCE | VORTICES | WAVES | CONDUIT | ORIGINE | ORIGINS | IMPACT | SEA | LAKE | RIVER | CANAL |
|--------|--------|------|--------|-------|-----------|----------|---------|-----------|---------|---------------|----------------|------|----------|-------------|-----------|------------|---------|-------|--------|--------|--------|--------|-------|-------|--------|--------|--------|
| 845 V  |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |
| 846 V  | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 863 V  | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 880 R  |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 894 R  | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 907 R  |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 910 V  |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 924 R  |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 979 V  |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1007 V | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1007 V |       |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1023 V | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1030 V |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1041 R |        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1051 RV|        |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1058 V | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1061 V | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1090 V | +      |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1098 R |       |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
| 1100 R |       |      |        |       |           |          |         |           |        |               |                |      |          |             |           |            |         |       |        |        |        |        |       |       |       |       |       |       |
This way of melting is quick because great flow is due to the steam generated by burning coals falling from the grid into the water, and going up through the flames of the coals. And this oven will be one braccio high and half braccio in diameter.

Drawing of oven with:

Coals - Grid - Smoke and air - Water

Two sketches of vessels:

Double - time 4° - Double - time one.

For the drawing you made Sunday, say in addition: that being the bellows of the same height and different diameter, what will the ratio be of the time to go down for the counterweight of one bellows relative to the time to go down for the other counterweight (?). And you will also say, for a container being drained by a lower tube and another being drained by an upper tube, what difference in filling time there will be when containers of equal volume are filled.

Each weight, by displacing water at rest, throws, or increases, at the surface as much
CA 835 R (X-1)
water as the volume of such weight, if the weight is due to water. But if it is heavy wood or lead, there is a difference.

* Such ratio will you find between the heights at which the water will raise in the tubes of equal diameter as it comes up from the bellows under pressure exerted by equal weights, as is the ratio of the dimensions of the opposite bellows.

* Such ratio will you find between the heights at which the water will raise in the tubes of equal diameter as it comes up from the bellows under pressure exerted by equal weights, as is the ratio of the dimensions of the opposite bellows.

CA 842 R  (307 r.b)  c. 1493-5

Drawing of dredge with a b - n m:

This is the way of dredging a port. The excavating device m n will have in its front teeth in the form of ploughshares and a knife. And such device will take a great load of mud. And it will have the back perforated like a net, so that the water be not retained in the box. And such a box will be moved over the place to be excavated, with a boat. Once it reaches the bottom, the winch b will pull it under the winch a, which will raise it full up to its beam. Then the boat will get under it and receive the mud from
the box, since such box can be open underneath and discharge the mud in the boat placed underneath.

Device, in the margin:
To take away the earth.

To the left:
The (bird) does the climbing with reflected motion with wings and tail completely open and the descent with incident motion with wings and tail closed in great part.

The pens and feathers under the wings have flexible or bendable ends, at the ends of the wings and the tail. In the front (of the wings), where the air is split, they are hard.
For aeronautics and related topics, see Giacomelli 1936.
Only a fragment of the text in this folio is included here because it is considered of fluid-mechanical general value. The first sentence, in between parentheses, is an abridged version of a longer one of Leonardo:

(If the bird would fall vertically, that would go)...against the '4a del 2°' of the Elementi, where it was proved that any body falling freely through the air, falls in such a way that the heavier part becomes the guide of the motion. And here, the heavier part is in the middle of the two open wings, i.e. in the middle of the 2 lighter parts. Hence, such a descent has been proven to be impossible.

Nature has determined that all the big birds fly at great altitude. There the wind favors the flight, being straight and powerful. Flying low between mountains, could sometimes cause the destruction of the birds, because the wind there rotates and is always full of vortices and whirling motions.

In their beginning, things are frequently the cause of large movements. We see this in the great influence of an almost negligible small movement of the rudder in turning a very great ship heavily loaded, and with so much water weight acting on each side, and also
against the push of strong winds on its great sails. Hence we are sure that, with small movements of wings or tail, the birds can approach the wind from above or below. Thus they can, without beating the wings, stay afloat in the wind, avoiding the fall.
A model (without water !) exists at the Science Museum Leonardo da Vinci in Milano, Italy.
Along the margin:

Similarly, the motion of the water flowing through the interstices of the granular earth are the life of the Earth. And the water climbs up and pours through the cracks of the mountain tops similarly to the sap shed by the (pruned) vine which climbs up and pours through the cut branches.

Similarly the waters move from down up pouring through the cracks of the tops of very high mountains.

Like the sap, pouring out from the cut vine, desires nothing else than the center of the world and moves toward it, so do the waters, pouring from the heights of the mountains, they willingly move toward such center.

Like the sap from the cut vine, which falls on its roots and penetrates in them to raise again back to the cut, thus the water which falls from the mountain tops penetrates the interstices of the Earth and returns (to the mountain tops).
Laboratory Methodology
Flow downstream from obstacles
in an experimental flume
Institut für Hydromechanik
Karlsruhe
Up above, to the right:

Motion of a weight

Motion of a spherical weight in the air. Two are the motions a spherical weight can do through the air; one is said simple and the other composite. Simple is that motion in which the surface of the body and the center move equally. Composite is that motion in which the surface of the body has a higher velocity than its center.

The simple motion is transformed into composite motion if the motion is prevented on any side.

In the long term, the composite motion in the air becomes simple. And this happens if the cause of the simple motion was more potent than that of the composite motion.

And this can be seen in any wheel to which a rotatory 'inpeto' is given; (the rotation) does not last a long time and diminishes all the time.

The 'potentia' of the friction on a plane (surface) amounts to one fourth of the weight of object (moved against) friction.
Marinoni (1980) sees in D6 "una ciocca di capelli". Knowing about Leonardo's rheograms (Macagno 1984), D6 could be the ondulated path of a falling sphere, or meanders in a river, or several other things.
To the right, drawing of waves:

Where the water runs down in contact with earth, it scours its bottom, and where it rises it deposits its load (of sediment).

After rotating the page on its left side, a passage whose first sentence is by other hand than Leonardo's (according to Marinoni):

(Any impetuous motion bends in front of the lesser resistance escaping from the larger one). And when the resistance is even it penetrates with its lesser side.

Folio upside-down. Sketches for a fountain:

Always the incident motion is more potent than the reflected motion.

In the cross-sectional sketch:

water - water - aria
In D4, I have emphasized some rheograms (stagnation and vortex). The orientation of D9 is conjectural.

I suggest that D3 and D4 are related.
There is *little* on fluid mechanics in this folio on a perpetual motion machine based on circulation of water from pump to hydraulic mover to pump, and so on and so forth.

Left-hand-side column:

•  •  •  •  •  •

This machine is in *continual motion*....

•  •  •  •  •  •

And *circulating* in this way, this water remains in motion as long as the *members of this device* are connected together, similarly to *living animal bodies*.
Dl has been highly simplified relatively to the original.

See Marinoni (1980) for a detailed description.
Any portion of water which is contained desires to fall (along) the vertical line.

Being prevented (from doing it) the water always exerts force on its support; and that support will be more loaded who will be under a longer line of water.

Communicating vessels

Water that puts pressure on water $b n a$. $a b$ are of equal weight. And here there is a function of balance whose axis is $n$.

Similar figure with $g f$:
I ask whether $f g$ are of equal weight.

Double figure of siphon with $m$ - water - $c$ - $f r$ - water; $c$ - $f$ - $r$:

When the water $r$ is equal to $f$ in elevation, $m$ plays, between these two conduits, the role of axis of the balance, and the water $r m$ will weigh the same as the water $m f$. The water in the vessel $c$ will rest on the curves of its bottom. If the bottom of that vessel is broken, water will fall in $r$. 

More paradoxical siphons in Codex Hammer 3B.
Siphon with b - S a - water:
The water $a h S$ will not flow, because the water $a h$ weighs the same as the water $h S$. The line $a S$ is horizontal and water on a horizontal plane does not move by itself.

Siphon with b S - r:
The flow of the water through the siphon $S b$ $r$ is the same as the flow that would go through $r S$.

Siphon with l n - o:
The water in the siphon $o l n$ will not flow permanently because...

Small sketch with the comment:
With no good effect.

Siphon with f - K - l
This will function as if the line $f K$ were somewhat shorter than the line $l f$. Make the line $f K$ as if it were straight, i.e. equal to the distance from $K$ to $l$.

Siphon with a - t m:
Some people have been of the opinion that, because the water in the tube $m a$ is of more weight than that in the tube $a t$, $a m$ must let its water flow in a continual manner.
See discussion in Rac. Vin. XXII (Macagno 1987).
Siphon with $f - s - h$:

This one has believed that the water $S f$, weighing more than that in $f h$, will flow down, while $f h$ will not, provided that, when the orifices $S$ are open, water pours out without air creeping in. And surely, the water $S f$ will fall down, but not the water $f h$. 
CA 882 V  (X-12)
Of the impossibility of the continual motion.

Drawing of a balance with b - 1 8 - l c m a n - f r d m e - s

As much is done by the lesser weight on the longer arm as what is done by the larger weight on the lesser arm. The water under water loses the weight it had in the air.

In the lever n a 1 is in balance with 8 in the counterlever n a because of the 'settima' which says: "the ratio of the weights resisting the descent of one another is similar to that of the arms of the equilibrium but it is the inverse", i.e. the larger weight on the lesser arm, and the lesser weight on the longer arm.

Now, here no motion is generated, unless some excess is added, which can occur in 4 ways. Two are in the arms of the balance; i.e. either reduce the lesser arm, or increase the longer arm. The other two consist in either increasing the weight of the longer arm or reducing the weight of the lesser arm.

But if the longer arm is increased, the motion of its end will be less, and less will be the motion of the lesser arm, and consequently the water poured by tube will be less.
Sketch of spiral tube:

* Of the simple helical pipes, equal in diameter of pipe and length, the one with easier motion will be that with lesser size.

* Of the simple helical pipes, equal in length and size, that one will yield less quantity of water which has the pipe of greater width.

** Of all (the pipes), that one will convey less water to a given height, which has larger tube, and this, one can understand.
* It is impossible that the water that moves up in the air through a tube of uniform diameter be of greater weight than that of the water which drives it.

* Of the water applying a pressure, only that part with the same diameter as that going up the tube is the one that pushes up the ascending water.

Drawing--without text--of an experimental arrangement to measure the force of a water jet falling down from a reservoir.

Halfway on the right-hand-side column:

* This **property** of the water relates to the generation of drops and **opposes** the **tenacity** of the water with the weight of the **filament** of such water. And when the weight is not present, the water **collects** and **becomes shorter and thicker**, then regains weight and becomes **distended and the filament, due to the thinness, breaks, vanquished by the weight of the water underneath which with such weight extends itself. And the filament is broken by excess weight, because the water continually diminishes its **flow** into the filament. And there is more weight in the filament than in the water which **forms the string of drops**. But when the **rain** increases, the filament gives more than what it gains, and the contrary happens then.

* The very **fine filaments** are made up of **minimal droplets**, which result from percussions of the waves due to reflections of the different **intersecting courses of the waters**.

**Water jet with d - c - b - a:**

* When the **filament breaks**, the same is done by the rest of it. The same is done by all of it. This is because each part tends to become spherical. And the upper part which is closer to its **source** becomes **nutrimiento**
greater. And since it follows the 3 spheres below, it attracts them as a body. And the second does the same with the third, and the third with the fourth. And the spaces in between, which they maintain together, are those of the water which becomes such spheres always increasing as they go up. Until they coalesce forming the drop above, which having regained the weight from below and above, becomes longer again and does the same which did before.

Folio upside down:

* The movers together with the bodies that they move, are of (2) natures, of which one is fluid and rare, and the other is dense. And in one and the other kinds the moved (body) is connected to the 'potentia' of its mover. Such connections are of two natures. In one the dense moved (body) is connected to the dense mover. In the other, the moved (body) gets connected to the mover, through a medium. E.g., the solar body, by means of its rays, evaporates the humid, which then moves through the still air, as it is done by the smell, or the heat, or the cold.
Laboratory Methodology
Flow downstream from obstacles
in an experimental flume
Institut für Hydromechanik
Karlsruhe
Right-hand-side column:

These many ditches carry the same water, or little less, than the water which would pass through the equivalent great canal. And there is no other difference but the time needed to excavate the ground, when the canals are made. This is so, because the (earth) flows between the sides, and it is not thrown out of the (small) ditches. This cannot happen when the water flows through one single canal. It is, hence, a useful thing to make them form the water stream by moving the earth underneath (the water). It follows that crossing such small channels will be easy.

Left-hand-side column:

Drawing of river and canals with d - f - a - K - c - b g - h:

By the 'nona', e f g h, the curvature of the canal will produce greater depth on the concave side than in the opposite convex side. Because of this, you can see that such main canal will always easily provide its waters to the small ditches placed on the convex part.

And because of the 'quinta' of the "maximum depth of rivers", the water of the river
D1 and D4 are similar to D5. I believe Leonardo knew what the effect of the curvature produces, but the text is unclear.
should be passed (back?) at the beginning of its current, where the curvature of the river is less.

The depth of the channels must be equal to the lesser depth of the river, i.e. (that?) at the beginning of the current. And you will be able to judge that all the water passing through that part of the river will be able to pass through canals of the same depth, if the total of their widths is equal to the width at the beginning of the said stream. The small canals will be able to convey all the water being somewhat less deep in as much as they will be quite shorter than the course made originally by the water of the entire river.

CA 899 V (328 v.a) c. 1508-10

The text in this folio is difficult to read, but some statements of interest in fluid mechanics have been extracted concerning flow of air through porous material.

* ...outside there is dilation..there is a kind of vacuum..

* the compressed air expels through the fine porosity the excess air, and the opposite porosity sucks in another air...
* Any body which is 'elementato' is porous. Hence the wood is porous, and if it is curved, the one half...

...one part is condensed, the other is rarified...the condensed part pushes, the rarified part pulls...if the arch is left with curvature for some time, the rarefaction will condense...and the condensation will be rarified, thus the arch will remain with the curvature.
Right-hand-side column:

The surface of the Red Sea is level with that of the Ocean.

And the Mediterranean became light both in the bottom which descended and in the surface (which went down with respect to the) original water level.

Due to the diminished waters the weight was less and the earth raised and changed the center of gravity (of the Earth).

The sea waters that descended from the Mediterranean Sea into the Ocean dug the bottom much below the surface of the Ocean due to the immense percussion on that bottom. Such digging did move back much with its fall to the point that finally the 'Gadetano' canal, which we see today, was formed.

A mountain may have fallen and closed the mouth of the Red Sea and prevented the discharge of the Mediterranean. Thus dammed up, that sea had as exit the 'Gadetani' straights. In our time we have seen similarly, a mountain of seven 'miglia' come down and close a valley and originate a lake. In this way have been created most mountain lakes, like the lakes of Garda Como, Lugano, and Maggiore.

The Mediterranean, after the 'Gadetano' cut went down little in its shores at Siria, and much at the cut, because before that cut the Mediterranean discharged the 'scirocco' way,
and thereafter started running down towards the 'Gadetano' cut.

*Drawing of the basin of the Mediterranean with a:*  
In *fell* the water of the Mediterranean in the Ocean.

*Left-hand-side column:*

All the *plains* between the sea and the mountains have been covered with salt water.

Each valley is *carved* by its river, and the proportion is from valley to valley as it is from river to river.

The *maximum river* of our world is the Mediterranean made into a river from the beginning of the Nile to the occidental Ocean.

Its supreme height is in exterior 'Mauretania' and its length is 10 thousand 'miglia', before going home to his Ocean, the father of the waters. This is 3000 the Mediterranean, 3000 the known Nile, and 3000 the Nile that runs toward the east, etc.
CA 901 V  (New)  c. 1515

To the left:

* The thunderbolt does (no) go straight because always the evaporation of the air (which becomes envelope of its motion) becomes fire and acts as an envelope.

CA 903 V  (330 v.a)  c. 1513-15

This page deals with the transformation of one solid into another with conservation of the volume. In agreement with Marinoni, the emphasis is here on the sketch of a body of generic form which is supposed to be given different geometric shapes while the volume remains unchanged.

* From a given quantity which is deformable make a pyramid with a given square base. The height must be found. (Also), from a given deformable quantity make a pyramid of given height. Find the size of the base....
Laboratory Methodology
Flow downstream from obstacles in an experimental flume
Institut für Hydromechanik
Karlsruhe
Right-hand-side column.

Two spheres at the end of a cord, one in a cylinder, with: focho in alto

Fire above

Mouth of a port:

Entrance to a harbor with two wing walls such that the wind does not fill such mouth with sand discharging from the shore dune.

Two pumps:

Make the supporting feet of the 2 pumps so that the mud does not prevent the entry of the water into the pumps.

This one would not empty the water down to its bottom.

Dredge mounted on boats:

This one does not pour the earth from upper part of the buckets going up.

Another dredge with: 3

Spokes of 3 'braccia'
Soils of the Adige to be bored.

Of the matter that makes the water turbid: it has the fall velocity larger or smaller depending on being heavier or lighter.
D1
D3
D2
D4
D5

CA 904 V (X-25)

suoli dell'adice
* The course of a given river will have longer bed, and hence a longer journey the less quantity of water it receives.

Water

The river with slower motion will have a course with the longer bed (will have longer way to go).

* The shorter river will be the one with faster running water.

* It follows from these 2 conclusions that a river which continually receives more water will have a more straight course.

Drawing of meandering river with d a - g b - f c:

* One can see here that when the river a d b g c f is full, is much shorter than the course d b f with little water in so much width of river.

* The floods make the rivers come out of their beds to form several concavities along which they trace their course after the said floods. And they abandon their old bed.

* The larger the flood in a river the flatter will the bottom be.
* The river with less water will have a more varied bottom, with different depths (of water).

**Between two fluvial sketches:**

When the river is big, it will be quite flat; the three gulfs (?) or concavities \(a\ b\ c\), \(golfi\) will be filled with sand.

**CA 913 R** (335 r.c) c. 1508-10

**Three figures of rotating arms, with \(b\ c\ a\); \(e\ f\ g\):**

On motion

The body in **rotatory** motion will move for a shorter time than the body moving in a straight line. This can be seen observing the water wheels which **entrain** the **surrounding air** and generate a great wind. Hence the balls from the bombards, which **travel rotat-ing** around their centers, have a **shorter reach** than those which do not rotate. [Figure]. Hence, make them with this **shape** and thus they will be of greater weight becoming adequate to the great 'potentia' of their motor. And this is better than putting two balls in the **artillery**, etc.
The same body will appear to be of less or greater weight depending on being in a medium of less or more density. Proof: let us suspend two equal weights in the air from the equal arms of a balance. Then, without doubt, each will resist the descent of the other. But if one of such weights is submerged in water, while the other remains in the air, then the latter will appear as much heavier than the one submerged in the water, in the amount the water is denser than the air.

And, hence, the ratio of media will be in inverse (value) to the ratio of weights. Unequal weights suspended from horizontal arms of the balance will not be (in balance?) in media of equal density. Proof: and assume that one weight be in the air and the other in the water, and that they balance each other: without doubt according to the previous (result) such weights must be different, and the lighter must be in the air.
This folio is valuable from the point of view of hydraulic engineering, but of interest to fluid mechanics there is only a short paragraph.

Up above:

Where a river due to its low level cannot enter in another, one must dam it to that elevation which allows the river to go down to the one which was higher before.

Effects of my rules

If you would tell me: "What is born from your rules? what are they good for?", I would answer: the rules act as reins on the engineers and researchers so that they do not promise to themselves or to others impossible things, acting as fools or as swindlers.
Rule to see that the water by its own action cannot lift itself.

Left-hand-side column. Vessel with:

2 - f e - 2, 20, 200, 1000 - d 10 1, 2 10 1
2/5 g - c b a - 1000 - h - goes up 10 'braccia'.

Here the water...

A long paragraph follows, which according to Marinoni constitutes a proof of the impossibility of perpetual motion. If so, it contains something of value from the mechanical point of view but there is nothing in this paragraph of real fluid-mechanical interest. It seems, then, enough to transcribe the section under the title "Conclusion".

Conclusion

I conclude that when water is raised due to the impact of (falling) water, the higher the water goes the thinner the continual flow tube (thus generated). And if one does not want the water that moves the wheel to fill the buckets, as in the French mills, the wheel will be slower since the resulting tube will yield the same (water) as above.
Go to 4 right-hand side column:

Now one must consider the 'potentia' of the impact which is inherent to the moving water and not to the continual tube that results. Hence, such resulting tube is so much thinner than that of the mover if the latter is devoid of impact. And if, however, you make the mover water affixed to that part of the wheel that is going down, I doubt that this is advantageous, because the water falling on the water contained in the buckets does not produce as an effective impact as if it were falling on a rigid body. Because the water yields when impacted, the impact is ineffective. And you gain in weight but miss the impact. Hence the weight counts as much as the impact.

Right-hand-side column:

This motion cannot continue, because the water, from the tank which generates the first motion, must always weigh more than that elevated which pours into the tank.
Laboratory Methodology
Waves in a pool due to triangular object
Fountain in Castle Park
Karlsruhe
Right-hand-side column. Candle between two mirrors:

Mirrors
If you place a candle between two long mirrors shaped like tiles, you will see such a candle able to melt any resistant thing.

Question
I want to understand what the weight is of one continual 'oncia' of water falling from a height of one 'braccio'. How much water can it raise in a continual (flow) to a height of 10 'braccia' using some instrument. And also to heights of 20 and 30, and so on, in the way of a general rule.

Impact
The impact on a place that does not resist is of little effect as demonstrated by the difference of falling (after jumping) on the toes rather than on the heels.

Left-hand-side column:
The thing that falls, will never produce the impact corresponding to its weight if, at the time of impact, it does (not) all stop at once.
Two impacting bodies with b a:

When b impacts, a is still falling.

The body falling will not give a perfect impact if the place of impact is not without motion.
CODEX ATLANTICUS

SECTION XI
* The same effect results from beating wings against the air at rest as the one on the wings without motion which receive the impact of the wind.

If a flat plate is mounted like an equal arms balance, on an axis and facing a uniform wind with its width, such balance will remain at rest.

But if the equal arms of the balance are impacted by a nonuniform wind, the arms will make half turn and will aligne themselves with the wind with the shorter arm facing the oncoming wind.

Sketch with c b:
And if the balance has the arms of equal length but different shape, the balance will show the course of the wind.

Plate of unequal arms:
Equal 'potentie' working against equal resistances do not generate motion.

Similar figure with b - c:
Equal 'potentie' working against different resistances displace the weaker.
Folio upside down:

Of the impact.

Of impact of fluid elements.

The fluid elements are in 'potentia' of being indefinitely compressed.
The adversary says that the thing that falls does not weight if it is not in air. The answer is: if the thing were not heavier than the air, it could not penetrate the air and it would be at rest. But any moving body penetrates with its excedent the medium through which it moves. Hence, the weight in a balance, that is going down, it does so with the velocity with which its excedent would fall, being the excedent of magnitude equal to its whole.

Below:

Question: Does the very great excedent augment the weight in the motion of its correspondent weight? Yes, because of the excessive velocity which is not proper to it. The air above compresses it with higher density the higher is the velocity of the moving body than the natural velocity of the air.

But the cord breaks always at the border line between the natural and the accidental motion at the place of the condensed contact of the pulley, where the weight of the two cords is acting.
The calculator errs in calculating the resistance of the air, since he does not take into account that the faster body compresses in front of it more the air in its motion than the slower body.

*(A thing) unless it remains rigid upon the point of impact, it will not give a percussion of too much amount.*

*A (composite) body with several links connecting (its parts) will give a percussion of a value corresponding to the part that hits (the target).*
Laboratory Methodology
Jet-induced vortices in a water pool
Institut für Hydromechanik
Karlsruhe
Right-hand-side column:

* I doubt whether the bag has higher velocity of ascent in a great expanse of water or in a narrow one, given the same depth (in both cases).

* It is doubtful that the bag would have greater ascensional velocity in the greater than in the smaller depth of water.

* There is yet a doubt about the ascent of the bag being faster in wide water than in narrow one.

In the wide one, because the narrow one could be so narrow that the bag could not go up.

Drawing of water falling in water:

The water falling vertically into streaming water makes the penetration along a curve, and its rising is curved also. The upper part of the rising part is not in the middle of the base of such boiling; base which is of oval shape.
D1
D4  D3  D2
D5
D8  D7  D6
D9

CA 943 R  (XI-5)

See also CA 782R-V, 790R, 1011R.
Sketch of a jet coming down from an orifice, with the letters a - c - b:

Whether the falling water a b is faster in c b than in a b.

c b is __faster__ than a b because over the same length c b is __thinner__ than a b. And the same I say of the motions of uniform __inclination__ (or slope?) and width in rivers.
Right-hand-side column:

**Coins falling in a vessel:**

* * * * * * *

After a glass is filled to capacity with water, put in it coins up to 3 'lire'; but you must drop them one by one and edgewise. **per taglio**

**Bottle upside down in a water bowl:**

* * * * * * *

Put a (balloon) **bottle upsidedown in a water bowl,** and in the bottom put a burning coal. **ghuasstada**

It will have enough power for its heat to pull up the water and fill such bottle. **chatino charbon di fuocho**
To the right, vessel with blower:

Water motion

When it overflows here, plug immediately because everything will be full.

To the right of drawing:

As soon as everything is filled one must plug here, and when you plug this one, plug (also) the one above; and when the one above overflows, plug it and plug also the one below.

Under the drawing:

Here, a valve inside, where the bellows is connected. And this bellows introduces water instead of air. And such water should be forced in such quantity as to fill the triangle and all the other containers. Afterward, pull the bellows toward you and the valve will close inside.
<table>
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<th>CA 971 V (XI-8)</th>
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</table>
Rotating container:

This screw has 100 turns and contains 10 'brente', which in friction become 1/4, which is 25 'brente'. And, in a complete turn, it pours one 'brenta', which must be that much away from the center of its circular motion as to exert enough weight that passes 25 times itself.
Vertical bellows connected to spherical reservoirs, with the weight $m = 100000$ 'libbre' and the orifice $n$, in the bottom of the vessel $a$, is contained 100 times in such vessel, the hundredth of such weight will exert a force on such orifice, i.e., 100 'libbre'. And following this same rule, the vessel $b$ underneath would exert a force on the orifice $o$ in the amount of one 'libbra'. And continuing with this line of thought, the weight placed upon the first vessel $a$ would exert on the last vessel $c$ at the orifice $p$ a force of $1/8$ 'd'concia' and $1/3$ and no more.

The explanation for this is that one can see in the inflation of balls and in the deflation of bellows the force of the air pushing uniformly on any of the resistances opposed to the enclosed air. And all the force exerted by the air from inside on the leather of the bellows, wherever it pushes, it displaces uniformly outward such skin which offers resistance (to the air).

And if such bellows would have in different places of its surface several orifices similar to the one before, and if they were all of the same dimensions, they would blow like the one before and they would distribute uniformly the air enclosed in the bellows. Hence the air exerts uniform force on the wall that encloses it; since it would be distributed uniformly through equal orifices.
**Vertical bellows with nozzles:**

100,000 - n

The orifice $n$ is contained ten thousand times in all the bellows, hence there is a force of one libbra in $n$. Among the bellows of different sizes but of equal tubes loaded by equal weights, the one of smaller size will expel the air out of itself with greater impeto.

100,000 - m

The orifice $m$ is contained 100 times in the bellows; hence the ten thousand 'libbre' exerting pressure from above produce in $m$ a force of 100 'libbre'.

I say something new about the bellows above: if the vessel in the middle is full of air, and (this vessel) is being filled with air from the upper bellows, it will discharge air with the same rate of flow, given that the inlet orifice be equal to the outlet orifice. And this is a correct statement, and the one above is false. But one can propose that in the way of a challenge. And so is (now) the definition of that (passage).

---

**Of impact as cause of fire**

If you would beat a thick iron wire with frequent hammer blows, making sure the wire remains on the same place of the anvil, you will be able to light a match in that place.
CA 974 V (352 v.a) c. 1490-2 (or slightly later)

Sketch of water course:

The canals of Milano drop one 'braccio', or so, per 'miglio'. And it is found, (however) that one oncia per 'miglio' is enough for the surface motion of the water. Moreover, if one gives one 'braccio' per 'miglio' over 400 'miglia', such rule would make the water turn backwards, because the world...

CA 978b V (353 v.c) c. 1513-14

The bending in the motion of the lightning shows it to us, as demonstrated in by book on movements, because its...

The waters from rains and rivers going into the Mediterranean, flow into the ocean through the 'Gadetano' straights with a defect (flow) equal to the water drawn by the (Earth) veins and evaporated by the sun. And this excess is the cause of the flux and reflux, because during the Mediterranean swells up due to the reflection of the ocean,
CA 974 V (XI-12)
and when the Mediterranean discharges (its waters).

Part of this page contains a long calculation (studied by Marinoni) concerning the radii of the elemental spheres. Some fragments are included here because they have relevance for a study of Leonardian fluid mechanics.

Left-hand-side page:

* That wave is going to be the larger which is generated by the faster motor. Hence, the air wave at the top (of its sphere) is enormous. Such wave is driven by the motion of the neighboring fire sphere, which moves at a speed of more than a thousand mile per hour. Here, I assume that, as concluded by the ancient (scholars) that the air sphere is ten times the water sphere...
Leonardo acknowledged the use of rheograms (Macagno 1984) in his studies of flow and transport phenomena (see, e.g. Windsor 12579). D3 is a good example of the use of rheograms. I have recognized in D3, at least, seven kinds of rheograms (from that of uniform flow to that of a boil.)
Upper margin:

The 'impeto' follows its line through the motionless wave due to the very great water current. It does it not differently from the ray of the Sun going through the winds.

The 'impeto' wave is sometimes a still wave in the midst of the very great current of water, and sometimes is a very fast wave in the motionless water, i.e. on the surface of the swamps.

Why a (single) percussion on the water makes several waves?

Center, left page:

* A motion has no reflection, if it is not stopped by an object impenetrable to the motion.

* The impact of each circular wave, generated in a still water pool, is reflected toward its origin.

* Each circular wave is reflected toward its origin in that portion which is missing and would complete the greatest circle.

Wave pattern diagram with c f e - a - c h d:

* The motion of the wave h a encounters the motion of the wave c a at the point a.
Paragraph illustrated by a breaking wave:

Of rivers

The water falls from a certain line of the crest of its wave, and it is faster where such fall is less inclined, and it breaks into more foam the more resistance it finds.

Hence, because of what has been said, the waves break against the course of the river, and never along the course of the river, because the water falling over the current cannot bounce from the material which runs away and does not receive the impact. But in the opposite fall toward the course of the water, the water falling from the wave against the course of the river does not find water running away from the impact, but coming against such fall. Hence if the fall of the wave is of 4 degrees of velocity, and the water coming against it is also 4 degrees of velocity, the impact occurs with 8 degrees of velocity. But the waves in rivers break against the current and those of the sea break against the water that returns from the shore where it is impacted and not against the wind pushing it.
Painters are mistaken in many cases when they depict water because they make the water see what the man sees; but the water sees an object from one side and man sees it from another. Many times it happens that the painter sees something from above while the water sees it from below. Thus, one object is seen from the front and the back, from above and from below, because the water shows the image of the object in one way and the eye sees it in another (way).

Of ebb and flow of the waters.

Any motion of water presents flux and reflux in any part of the river where the flow velocity is diminished. Proof: where the course of the water is steeper, the water is faster; and where it is flatter, the water is slower. Hence the flat pool receives more water than that it discharges. Because of this it becomes necessary that the water of such pool acquire height enough for its weight to overcome the water impacting it. And then such pushed water comes down from that height around the base of such hill and that part, coming down against the above mentioned current, dams up such current in such a way that
Laboratory Methodology
Patterns induced by jets in a water pool
City public fountains
Karlsruhe
the upper water of such current is retarded until the successive water becomes superabundant and overcomes the reflux and originates a new flux.

Impact of two spheres, with 8 7:
The impact made on an object which is escaping in front of the percussor object, is of little amount. But if it is made on an object moving against the percussor object, it will be of great amount. When the percussion is made upon a motionless object, such object receives an impact of intermediate 'potentia'. The impact on a rapidly rotating wheel will amount to little, especially if the percussor and the wheel have equal motion.
One can see in the eddying currents of the winds how flocks of birds are coming from faraway countries. And one could sometimes barely see them because in their revolutions one would sometimes see them all in side view, i.e. in minimal size. And, at other times, they would present the maximal size, i.e. in frontal view. At the beginning they would be sighted in the form of hardly visible cloud, while the second and third flocks would become more noticeable as they would come closer to the eye looking at them.

And the closer of the said flocks came down obliquely to land on the dead bodies, carried by the waves of the deluge, to feed on them. And this they did until the light weight of the inflated bodies would cease. Then the bodies would sink slowly to the bottom of the waters.

The water does not weigh upon its bottom unless it impacts the bottom.

The rain falling on the soil, changes the location of the earth (which existed around the center of the world) from its place.
Laboratory Methodology
Pattern induced by falling nappe in a water pool
City public fountains
Karlsruhe
Procedure for clear distillation. Make the water flow all around the still.
Each impression is conserved in the sensitive receptor; and the longer the persistence will be, the greater the 'potentia' (of the impression); and the shorter the less 'potent'. In this case I call sensitive that object that receiving some impression changes relative to what it was; insensitive object is the one which upon reacting to an impression, which produces some change, does not retain anything of it. A sensitive impression is that of the impact received by a sonorous thing, as the bells and similar things, as the voice in the ear. If the ear would not conserve an impression of the voice, no song would please, because when going from the first to the fifth voice the ear would act as if it would hear simultaneously both voices, and thus senses the consonance of the first with the fifth. And if the impression of the first would not stay in the ear for some time, the fifth, which follows immediately the first, would appear as being alone, and just one voice does not produce any consonance, and thus any song all alone would not please. Also the light of the sun, or of another luminous (body), remains in the eye after seeing it. And when a single stick on fire is quickly moved in a circle, such a circle seems to become continuous and of uniform fire. The rain drops appear as continuous filaments, when they come down from their clouds. And thus it is shown that the eye conserves the impression of the moving...
things that the eye sees. (Among) the things which do not conserve the impressions of things presented to them, we have the mirrors and any polished surface. As soon as the things causing an impression are removed, (the mirror) is deprived of the image. Hence we will conclude: the motion of the motor impressed in the body moved by such motor is what moves such body through the medium through which it is moving.

In addition, among the persistent impressions, we can include the waves and the vortices of water (currents) and winds in the air. Also the knife stuck into the top of the table, which is bent and then released long conserves a vibrating motion. These are all motions reflected from some other (motion) which can be said incidents up to the vertical of the place where the said knife point inserted in the table top. The voice in the air is impressed without saturation of the air, and impacts on objects and then returns back to its source.

The impacts of liquid bodies on solid bodies are of different nature than the before mentioned impacts. And still different are the impacts of liquids on liquids. The impact of liquids on solids is an experience at the sea shores, which receive waters against their stones that are dragged toward the steep beaches. It happens frequently that the wave is not yet halfway and already the stones carried by it return to the sea from which they departed. Their destruction is increased by the 'potentia' of the wave which falls back on the beaches and...
On this page we find several statements on rotation after impact. Some of the statements may have an interest for the aerodynamics of rotating bodies, and perhaps also for generation of rotation of impacting liquid bodies.

The rapid rotation of bodies of general shape is the cause for such bodies to look like spheres (in their motion?) and to behave as having perfect roundness.

Any part of the surface of a body traverses more length after acute impact than its (own) center.

The body launched by curved motion makes a curved path.
Laboratory Methodology
Pattern induced by jet falling
in a water pool
City public fountains
Karlsruhe
Right-hand-side half:

Of rivers

The river with continual lowness (or depth) in the middle of its course, will maintain its banks.

Canal over a river:

Lock

Of rivers

Where the canal is narrower, the water flows faster than anywhere else. As the water comes out of the narrow section, it expands furiously impacting and eroding the neighboring sides, and often (the river) changes course from one side to the other. Of the current in the straits of Spain.

East Mediterranean:

a-bm-cnx-do-e - Mediterranean Sea.

Left-hand-side column, seventh line:

The larger ships that are made, are $7\frac{1}{2}$ 'braccia' wide, 42 'braccia' long and with parapet $1\frac{1}{2}$ 'braccia' high... When one begins, one makes a narrow ditch to see the water level and then...
<table>
<thead>
<tr>
<th>D1</th>
<th>CA 1007 R (XI-23)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D2</strong></td>
<td>D2, 3, 4, 6 complement D1 with details, or similar hydraulic works. (Also 126V.)</td>
</tr>
<tr>
<td><strong>D3</strong></td>
<td></td>
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<tr>
<td><strong>D4</strong></td>
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<td><strong>D5</strong></td>
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<tr>
<td><strong>D6</strong></td>
<td></td>
</tr>
<tr>
<td><strong>D7</strong></td>
<td>See also MsA 57R and discussion by Macagno, in IHHR I.R. on &quot;Eulerian-Lagrangian views in Leonardo&quot;.</td>
</tr>
</tbody>
</table>
Of rivers

Proposition - 'The river running along a non-uniform course has non-uniform depth and width'. The reason is that the section of the river moving over a steeper bottom runs faster, and after that slope impacts the following part, and picks up the gravel and...

Of rivers

It takes it away and impacts with its 'impeto' the resisting bank. Where it happens that the water becomes flat between the course and the bank, and the surface of the oncoming water makes an 'impeto' in the surface of the flat water, and thus...

Rivers

The surface and the bottom of the oncoming water find resistance at the surface of the water of less velocity (than the oncoming one) and of higher bottom.

Of rivers

And immediately turns transversely using its 'impeto' to generate vortices which erode the neighboring banks.

The vortex will be of maximum circuit in the part where...

To the right, vortices:

Rivers

If the uncontrolled course is in the middle, it will produce two contrary vortices which will erode the banks they impact.
6 - which after a short time will fall on top of the water filling the eroded bottom; and the impeto of the water will turn toward the opposite bank.

6 - and it will make a vortex, large as the sum of the first 2, and will make longer the bank in front of its center.
Laboratory Methodology
Pattern induced by jet falling
in a water pool
City public fountains
Karlsruhe
Up above, over the drawings:

The wind has similitude with the motion of the water.

What is the difference between the pulled water and the pushed water.

Pulled water, e.g., is that pulled by the ocean when it goes down and attracts behind itself the water from the Mediterranean Sea.

Pushed water is seen when the rivers flow into the sea and push its water.

Sketch of instrument:

To know where the water weighs (?).

Channels.

Observe the bed depths made (?) by the rivers along the banks.

* Fire is attracted by combustibles and water by lowness. The combustibles are disunited and separated and the fire dies where there is no nutriment (for it). The slope of the valleys is united and united will be the damage caused by the river flow, until it ends into the sea, only place of rest.

* The inclined plains end together with the courses of their rivers in the sea, universal low place and only still place for the wandering waters of the rivers.
Marinoni (1980) sees an analogy between fluvial hydraulics and the flow of air between two clouds. This would imply that Leonardo believed that clouds could stand still and the air flow in between two of them. I believe this is one of many passage that would be better left to scientists to study and interpret.
While the fire is fed by wood, the flow of the water is maintained by the sloping plain, which ends at the sea shore, and there ends the flow of the rivers.

Taking away from men the light things able to be carried with its furor and ruining the heavy things.

The universal movement of the water of constant depth, will have higher velocity in one place than in another, the closer to each other are the banks.

For a river of uniform depth, the ratio of velocities between a narrow section and a wide one, will be like that of the larger over the smaller width.

**Flow pattern with vortex:**

Water at 'Santo Storzo'.

**Left-hand-side column:**

The turbulent...

The stone makes in its bouncing more noise because it acquires a second motion, which derives from (both) motion and impact.

Among the things to be mostly feared by men, is the damaging flood of the running rivers.

It seems to me that among the scaring, damaging things, the supreme one is the river flood. With unpreventable 'impeto' the floods ruin the human possessions.
CA 1007 V (XI-27)

acqua di San storzo
Sketch with three jets and a drop of water; with the letters a - n:

Why the water drop does not fall vertically under the angle $a$ as under $n$? And why when the water increases, it flows farther and farther from its angle?
Drawings with floating containers:

It is shown by experiment that given 2 equal volumes of water and air enclosed in 2 vessels joined together, and placing the air under the water of a pool and the water in the air - the water is then supported by the air.

But if the volume of water would be larger than the volume of air, then such water would push such air to the bottom of the pool.

When the air is being pushed down to the bottom of the pool, at each degree of descent acquires velocity of motion. And this happens because always there is more and more of the other water on top of the water going down with the air below.

*Water and tubes in a vessel, with m f h n - a b - p o - c - r q - d e - t g S*

The ascent of the water is equal to its descent.
Concerning D1,2 see Macagno 1982 (Scientia), 1989 (Rac. Vin.). This is a crucial experiment.
Drawings for a lock:

In 70 'braccia' put five locks and make that the water, pouring in, flow from the bottom of the pit under the other water, at right angle (under the water) i.e. that the junction of the centerline of the well, 12 'braccia' long be at right angles the line of water flow coming out from it.
Upper half of right-hand side page. Flow with two vortices, and \( m - n - b \):

Where the water is faster, it will have less depth; and conversely, it will be deeper where the velocity is less. Of course, the river must have constant width.

This is proven by the 'ottava del primo', which shows that the river, in any part of its length, passes the same quantity of water in equal times. The river can be of any possible variation: of width, of slope, of depth, of tortuosity.

The water impacts more the bottom when it falls from larger and higher wave.

The wave will be higher where the water stream ends with larger 'impeto' and where such 'impeto' finds slower water.

Upper margin in left-hand-side page:

** Where all the water of the river more...
   where the channel is more...

Where the river channel is more inclined the water runs faster; and where the water is faster it erodes and deepens more the bed of the river, and thus the same quantity of water occupies less width. The shorter the course of a river, the higher will be its velocity. And conversely, the river with longer course will be slower.
<table>
<thead>
<tr>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D5</th>
</tr>
</thead>
</table>

RHS

CA 1018 R (XI-31)
Where the canal is not deep enough to receive excessive water, of necessity the water will overflow the banks.

No part of an element weighs in its own element if such part is not moving with 'impe-to', or if it is not falling back after having been extracted from the element.

Water in a canal with \( mn - ea - b - fd \)

Water coming down some steps, with \( a - n \):

The flowing water does not erode its bottom as it does where, after such flow, it becomes quieter in its surface.

What has been said here happens because any part of the water flowing over its bed gives less weight from itself than that given by the length of such course on the impacted object.

It is proven in the figure beside. To this end: regarding the weight of the water \( a b \), will not be in \( b \), except for what amounts to the space \( a b \). But, because the element does not weigh within itself, and still less within the one heavier, we will conclude that such water does not erode its bed on account of gravity towards the center of the world, but in that much that enters in the air sphere, as it would be the part \( a e \), which in its upper part has entered the sphere of the air over the length of the space \( nb \), and the length \( de \) over what it is \( md \).
Hence, all the course $d \ e$ weighs as so much water on the bed $d$ as the same amount that would weigh a similar depth of water extending from $m$ to $d$; since the weight of such water $d$ is in continual motion, continually raises and jumps up, and then falls back in $d$. 
CODEX ATLANTICUS

SECTION XII
By the use of similar (?) quantities of water and stone there are almost infinite degrees of weights as many as the variety of densities. This could be done by taking first pure water, to which a very small amount of earth is then added, and thereafter more and more, until mud is obtained, then hard mud, and hard earth. Then go to more dense stones, up to the metals. All this I say because I need such things to give pressure to the water in its containers.

The water climbing up the mountains does it like the water that moves up the plants from the roots to the top, as demonstrated by the vines when they are pruned. The same does the blood in all the animals, (similar as they are) to the Earth, a living body.

If the water exerts a force on the walls of a parallel container, that (part) will miss from the (water) weight on the bottom of the container; i.e. the water does not load the bottom of the container with its entire weight.
<table>
<thead>
<tr>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>CA 1023 V (XII-1)</th>
</tr>
</thead>
</table>

(See XII-2)
Sketches of communicating vessels with (6) 3
1 2 (?) 6 - 3...

* It is impossible to raise dead water (with counter) weights in the same amount as the weight of the said counterweight, so that it would go up to the location of...

Sketch for experiment with balance:

Experiment

If you want to know if all the water, which is vertically above the orifice in the bottom of the vessel, weighs or not on such orifice, i.e., (maybe) the water partially pushes on the sides of the vessel, do the above indicated experiment.

Water-lifting device:

The water that moves up to the location of the counterweight which drives it, will never equal in weight the weight of such counterweight. Hence the time you spend in (the means of) raising such counterweight, use it in (devicing the means of) raising equal amount of water, and you will (also) save in the cost of the machines.

Communicating vessels with f - m - n - S r:

If the water n r exerts a partial pressure on the sides, it becomes short of weight on the bottom, and the same does in the tube f S. Now it must be seen which water has greater contact with its sides, and take into account
The device to measure the force $F$ in D8 is not clearly indicated by Leonardo.
Better sketches for D8, 11, 12 can be found in Codex Madrid I. (See discussion in Macagno 1982.)
I am not sure D2 belongs to this group of sketches.
only that one which exerts a load on its bottom, and forget the rest.

Sketch of vertical bellows with $h \cdot r \cdot m - 4 - p \cdot o \cdot b \cdot c - 1 - 1 - 1 K - 1 n$

Here it is shown that the counterweight cannot ever raise to the place from which it departs a weight of water equal to its own. The counterweight $m \cdot a$ weighs the same as the water $c \cdot n$, i.e. 4 times the weight of an equal (volume of) water. Hence the line of water, jumping above its own level, will be 4 times the line of the weight which pressurizes it. Once the counterweight has gone down all the way, the elevated water will be at the maximum height in $b$, and the container $o \cdot p$ will have collected all the water in $c \cdot n$, which in weight and elevation will equal those of the counterweight. It is impossible that the center of their gravity be at different elevations.
'Prima'. - The similar parts are not to be always equal to each other, but when we call them similar and equal they are similar in figure and equal in quantity.

'Seconda'. - The parts similar but unequal will have between them the same ratio existing among their wholes.
Laboratory Methodology
One of the many public fountains illustrates waves generated by weak erratic vertical jet
Karlsruhe
1. - The stone thrown into the water fills the water with (* waves) circles. (The stone) becomes the center of several circles which have as center the impacted point.

2. - And the air, similarly, becomes full of spheres, whose centers are the sounds and voices made in the air.

3. - Each body placed in luminous air fills the infinite parts of such air with its image and it is all in all (air?) and all in any part (of the air?) and its properties, over equidistant surrounding spaces, decay like...

How the water surrounds with circles the point impacted by the stone.

Where the stone impacts the surface of the water, it originates circles which decay as they become larger. And also the voice or the noise impacting the air propagates circularly in a similar way, and decays also since the (person) close to them hears better and the (person) far away fails to hear.

Drawing with intersection of visual lines:

Comparison of how things reach the eye

* In the way the stone thrown into the water becomes the center of several circles, the sound works in the air and sends (its action?) to the equidistant ears (around), (i.e.) it propagates circularly its voice.
CA 1041 R (XII-5)

finestra
The water and the air are (respectively) impacted by the voice and the stone. It is the water that shows, with its different circles around the place of impact, how the voice made in the air will be heard at equal distances (at the same time). In the same way are propagated the (optical?) properties of bodies to the infinite parts of the surrounding air.
Laboratory Methodology
Wave pattern generated by jet in a water pool
Karlsruhe
Make tomorrow cardboard figures of different shapes to be dropped into the air from the jetty. And then draw the paths traced by the objects, as they fall, at different places in their descent.

To the left, sketch with: Sun - a - d c - b:
In the antipods a c b the rivers flow and raise their waters, which do not evaporate. And in a b d waters go up in vaporization.

Sun in four positions around the Earth with b - n - a o p c - m - d:

a orient raises water from n m and conveys it to o.
b raises the water from p o and conveys it to n.
(c) occident raises the water n m and conveys it to p
(d) raises the water from p o and conveys it to m.

To the left, Earth with c - c b - a - h:
The weight of the water sphere is added (?) to the weight of the Earth.
To the right

The thunder of the bombard makes three motions of different velocities through the air. Of those motions, the fastest is the one which carries impression of its sound. Another, later, carries the wave generated by the percussion of the flame. The third is due to the ball thrown by the bombard.
Laboratory Methodology
Effects of a spur
on a meandering channel
Karlsruhe
To the left, Sun and Earth:

Where there is less heating, (the water) raises less.

Sketch of the Earth with taken away a - put b
d put f - c - taken away.

In a c is put by the rivers and taken away by
the Sun f. In d is put and taken up by the
sun; in b is put but not taken away.

The other page.

The Earth with a n - east e d - b m

'Prima'. - a b c is seen and heated by the
Sun, and its heated ends a b move at about
one thousand 'miglia' per hour, as it will be
clarified somewhere else.

'Seconda'. - The part of the sphere of the
water nearest to the surface center of the
Sun, which illuminates it, is the one which
is heated the most.

'Terza'. - The substance which has highest
density is the one which is most heated,
because of this the water is heated more than
the air, and the earth more than the water.

The more a water is heated the more it di-
lates.

Hence, by the 'seconda' above, it is shown
that c is heated more than a, because it is
closer to the surface center of the sun by 571 3/7 'miglia', which is the semidiameter of the sphere of the Earth.
Laboratory Methodology
Study of impinging jets
Karlsruhe
As much force is exerted with an object against the air, as with the air against the object.

See the wings impacting the air and sustaining the heavy eagle high up in the thin air close to the fire element. And see also the wind over the sea impacting the inflated sails and making run the loaded and heavy ship. Hence, with this demonstrative and explanatory reasons, can man know that, with ingenious and great wings which exert force against the resisting air, it is possible to harness (the air) and raise above it.

Man with parachute:

If a man hangs from a canopy of airtight linen cloth, 12 'braccia' wide and high, he will be able to jump from any great height without hurting himself.
See a somewhat better design of the XV C, in Add. British Museum 34113 f. 200V.
Left-hand-side column. Subdivision of the pyramid.

The pyramid cut by a plane parallel to the base at half way of its length, is divided in 7:1 ratio.

Several sketches of curves tubes used in water-lifting device:

The tube of uniform diameter, when curved in circular shape and with the diameter directed towards the center of the world, will hold water with equal weights on opposite sides of the diametral line of such circular tube. The same will happen when such circular tube is turned in any direction; i.e., always will the aforementioned diameter of the circular tube divide the water in two opposite equal weights. If the circular tube is cut and the two ends (thus obtained) are separated and do not meet anywhere, and then the tube is inclined, the center of gravity of the water in the tube will be out of the center of such tube toward the lower end of such tube.

The center of gravity of the water in the circular tube, which has been inclined, is farther away from the diameter of such circle (in proportion to how much) the lower one end of the cut tube is than the other.
D1 to D4 show subdivisions of pyramids and cubes. See original drawings for more detailed D1. (See Macagno M. 1987, 1989 for discussion of subdivisions into similar figures.)
Right-hand-side column:

The snow falling on \textit{varied shapes pads} them with different thicknesses depending on the \textit{slopes} of those shapes. Similarly, the \textit{sediments} carried by the river floods, after the waters come to a place of rest, settle upon the \textit{shapes} of the bottom of the waters and \textit{pad} them as in the \textit{analogous case} above, etc.

\textit{CA 1067 R} \hspace{1cm} (385 v.c) \hspace{1cm} c. 1513

\textit{Turn the folio around right side.} Right-hand-side half of folio:

\textit{Anaxagoras}

\textit{Any thing comes from any thing}, and from each thing a thing is made, and each thing turns into another thing because what is in the elements is made of such elements.

\textit{CA 1069 R} \hspace{1cm} (386 r.b) \hspace{1cm} c. 1480-2

\textit{Turn the folio on the right-hand-side.} \textit{High tower}:

\textit{varie globbuletie veste}

\textit{obliquita terra}

\textit{globbosita}

\textit{vestendo chompratione}
Flow patterns in CA 1098R
This tower must be completely filled with water.

Middle tower:
This tower must have a tank full of water on top.
To make this screw take bowels and inflate them, and let them dry, and then give cover of wax to them, and (finally) wrap them around a thin wooden rod.

Below, to the right water-lifting machine:
Water raised with the force of the wind.
This piston pump must have 2 valves, one in the pipe that draws the water, the other in the pipe that delivers it.

Machine to the left of the preceding one:
A method for forcing the water up
This way the water will be forced up into the house by means of conduits.

Upper half:
Method to force up the water by its (own) cause.

Sketch of another machine:
100 100 - 1/3 1/3 - 8 8 - 200 - lead - lead
Method to force water up.
The mechanical engineer, interested in water-lifting device, should study the originals of D1, D2, D3, D4, D5, D6, with many details of the mechanisms. D8 looks to me like a variation of Tantalus cup.
Four water-lifting screws:
Water lifting

Container on inclined plane:
Which must be filled

Lower left corner:
Method of drawing a great amount of water but the blades (?) must be more separated from the openings of the pump.
From two pages, otherwise unrelated to fluid mechanics, I made these two sketches because they show how flow was represented by Leonardo. (See Macagno 1991, London.)
Continual motion of water

9 - C A P - water - fine sand-earth mixture -
S - O - b - m

When you have poured water up to the point $g$, unplug the point $m$ at the foot of the mountain.

This is a way of having water at the summit of a mountain or another high place; and it is done as follows. You will make a siphon starting at the foot of the mountain, at a place where first you can make a water well. Then you start the siphon from the bottom of the well and go up to the summit of the mountain as shown in $m A$. And make the bottom in $A$ full of small holes. Then fill the space from $A$ to $b$ with fine earth-sand mixture (or with washed river sand).

Then make many other small holes in between $A b$ and $p S$ so that the water seeping through the sand can reach the container $p S$, and from there you will always have pure water. The tank must be large, and larger than $A b$, but before you put the sand, fill it with water and thus fill with water (also) the container $p S$.

Drawing of chimney:

Chimney that turns according to the wind; and closes during the night so that the air does not come in.
Cross-section of chimney:

air-pit

A way of making a chimney which does not produce smoke. You will make similar orifices.
Beautiful drawings of flow in the canal of San Cristofano (Milano). The nappes do not exist at the same time. One drawing illustrates in cross-section a family of curves with different time-parameter values.
CA 1097 R  (XII-18)
Water (currents) meeting at any angle always bounce back and vertically up. Afterward, with swirling motion they turn down towards the bottom.

The material conveyed by the flow impinges always on the bottom of the river and bounces back due to the reflected motion.

The larger the area on which a given body rests on the air, the less it weighs upon the air. This is taught to us by a coin of heavy gold which, when laminated into a very thin gild leaf, floats in the air at the slightest movement of such air.

*Bird with extended wings and d c a b:*

The concavity of the wings under the shoulders at the insertion of the wings receives the rotation of the air. And it has been thus conditioned by nature close to the beginning of the wings because of the 'quarta' of weight, where it says: "that part of a supporting element is more 'potent' which is closer to its beginning".

The motion of the air exerts the same action against the still object as the action by the moving object on the still air. The same happens in the water, for which I have learned that there is similar action in the lateral resistance of the rudder as that which accompanies the action on the sails of the ship.
Of fluid-mechanical interest are drawings D1 to D11. D12 is a group of architectural drawings.
Below, normal writing:

* The cause that drives the water through veins against the natural direction of its gravity, is the same that moves the humors of all species of animals.

Cross-section of oven with: bottom of oven - c b a - m n - e d - p o - r q - g f - h

a c d e are registers which bring air under the burning wood which is upon the holes o p. The wood is introduced at b. The smoke exits at n m. The ducts o p are where the fire comes in whirling around, together with the wind. q r is where the fire comes out of the oven. f g is where one observes the oven and where the bronze is introduced. h is where the bronze comes out.

Another oven with b a - S r - o c:
Here, \( a \ b \) is where the flame enters the oven. The 5 holes are where the fire comes out. \( r \ S \) is where the oven is fed with bronze. s'imbronza
Flow patterns in CA 1098R
Two flutes with b; a:

These two flutes do not make the changes of the voices by jumps, but in the manner of the human voice. And it is done by moving the hand up and down as in the curved trumpet, and mostly so in the whistle a. And one can make 1/8 and 1/16 tones and what one pleases.

Water (driven) blower:

If air flows through a uniform conduit and you introduce some air at one end, the same amount comes out at the other end.

To the left. Experiment with a flask:

The fire of a burning coal on the bottom of this flask will have the force to fill it with water.
Water bellows? or water-driven air-blower?

mantaco d’acqua

CA 1106 R (XII-22)
Head emitting vapor through tube in the mouth:

If this head is full of water up to the mouth, by boiling the water and letting the vapor come out through the mouth, it will have the power of lighting a fire.
For a head like this, see, e.g., Branca 1629.
The text is minimal, but the illustrations of interest to the fluid-mechanicist are many. One is indicated by Leonardo as a device of 'moto continuo'. Another seems to be a still. Many are siphons or contain siphons as part of a system.
There are about thirty drawings of this kind in CA 1113, waiting to be studied by interested fluid-mechanicists.