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Leonardo Studies: Progress Report and Long Term Plans August 1982

1. Introduction

These studies began in February 1973 under the auspices of the Wellcome Institute and the direction of Dr. K. D. Keele, M.D., F.R.C.P. while the author was writing a dissertation at the Warburg Institute in London. At the outset there was a simple question: whether Leonardo's claims concerning linear perspective were experimentally based. Repetition of several experiments described in the notebooks confirmed that this was the case.

It was decided that a comprehensive study of Leonardo's writings on perspective should be made. Meanwhile Dr. Keele had become engaged in preparing a new edition of the *Corpus of Anatomical Studies in the Collection of Her Majesty the Queen at Windsor Castle*. During the period 1975-1977 his involvement was, therefore, limited to fortnightly consulting sessions. From 1977 through 1982 these meetings took the form of intense 4-7 day sessions two or three times per year. As a result the would be assistant found himself much more centrally involved in the project than had been foreseen.

Since July 1975 generous support from the foundations Wellcome, Volkswagen, Alexander von Humboldt, Thyssen and ûerda Henkel has enabled continued research on a full-time basis. Without. this assistance the present studies would not have been possible.

Thus far volume one has been completed. Volume two will be finished within the next twelve months and a third volume is planned. Each of these will be briefly described. A future project will then be outlined and the implications thereof will be examined in turn.

2) Volume One

Volume one, *Linear Perspective and the Visual Dimensions of Science and Art*, 1,240 typewritten pages is complete (enclosure 1). It was forseen that Harvey Miller would publish this, but he has written to explain why this is not possible at present (enclosure 3). Alternatives are being explored. This first volume is divided into four parts.

I: Part 1: Context

Linear perspective is commonly seen as a handy trick by means of which one can represent objects realistically. Historians have therefore tended to treat its discovery as an event for which Brunelleschi (Panofsky, Parronchi, White, Edgerton) or Piero della Francesca (Wittkower) was responsible.

This study sets out to re-assess the phenomenon of linear perspective. It is claimed that its chief role lay therein that it served to build bridges between different levels of reality: a concrete object, a model thereof, a three dimensional version thereof, a figure and an abstract geometrical diagram thereof. In this view linear perspective is no longer a simple trick: it involves complex relations which could only be discovered gradually.

It is shown that while the early Renaissance thinkers from Brunelleschi through Piero della Francesca were acquainted with some of these relations, Leonardo da Vinci was the first to study them systematically. This led him to discover the inverse size/ distance law that Euclid and Piero had denied. In short, the quantitative laws of perspective that historians have assumed were discovered by Brunelleschi in the period 1415-1425 had a more gradual development and were not discovered until the period 1485-1492 by Leonardo.

It is shown that Leonardo built on the ideas of his predecessors and that his work had a definite impact in the generations that followed. The assumptions that Leonardo was an illiterate (Sarton) working in an intellectual vacuum (Lindberg) or that, because he did not publish, he had no impact (Hall) can thus be discarded.

It is also established that Leonardo performed actual experiments in arriving at his scientific insights. The chief perspectival experiments are reconstructed and it is shown that he has a definite approach that involves a systematic play of variables.

I: Part 2: Scientific consequences

It is claimed that Leonardo's approach can be seen in terms of a three-fold programme.

First, he set out to render the geometrical tradition naturally. Since Antiquity there had been a continuing interest in the regular Platonic and semi-regular Archimedean solids. But these had been treated as abstract problems in mathematics (Euclid, Pappus ... Piero della Francesca). Leonardo transforms this tradition by rendering them three-dimensionally in perspective.

This approach he extends to the whole of Euclidean geometry. Hence he makes models to illustrate the Pythsegorean theorem and changes what had been an abstract tradition of transformational geometry into a practical challenge involving clay or wire models.

A second stage in Leonardo's programme is to render the organic world of Nature geometrically and in particular, the human body. In searching for a method, he finds that he cannot simply copy the inner layers of a hand (or other anatomical part). He therefore makes a model of it with threads or wires for the nerves and veina and then uses this model as the basis for his drawings. This he evolves into a full-blown method.

Gombrich in his *Art and Illusion* has argued that making comes before matching and has assumed that the geometrical schemata as developed by Dúrer were largely a psyehologica consequence of the picture-making proces. In this study model-making emerges as a logical consequence of linear perspective and his dictum can thus be revised: model-making comes before matching. Implicit here also are philosophical implications of considerable import. Reconstruction comes before representation. The way to realism is therefore only possible through the artificial.

A third stage in Leonardo's programme lay in seeking to visualize and render three-dimensional various abstract forces of Nature such as concentration of heat, strength of wind, power of blow, change in impetus etc.

Ever since Antiquity there had been a tendency to regard an abstract, mathematical world of ideas (Plato) as opposed to a concrete organic world of matter (Aristotle). Leonardo's threefold programme effectively resolves this opposition. Given the bridges created by linear perspective, mathematics could now be studied naturally and Nature mathematically. This, it is claimed, has important consequences for the rise of early modern science.

I: Part 3: Artistic consequences

Here Leonardo’s notes on diminution of form perspective and colour perspective are examined. It is shown that he became aware of discrepancies between visual experience and linear perspective. In the case of an actual object, for example, one can see around the back of it. This is usually not possible in the case of a painted object.

Leonardo was, nonetheless, intent on achieving this visual effect in painting and therefore developed a special method of contrasting light and shade which he termed "chiaroscuro". Perspective and chiaroscuro together, he claimed, constituted the excellence of the science of the painting.

This preoccupation with chiaroscuro helps to explain why the late Leonardo becomes so fascinated with the contours of human form (*Mona Lisa, St John the Baptist, Leda*), and why he avoids the geometrical backdrops that we usually associate with perspective. In short an understanding of Leonardo's perspectival theories leads to a fresh assessment of his painting practice.

I: Part 4: Conclusion and Epilogue

Some of the consequences and larger implications of these studies are explored. It is suggested that Leonardo's perspectival interests help account for his concern with visualisation: why in his 6,500 pages of extant notes he should have made c. 100,000 sketches, diagrams and figures and why he ultimately preferred visual over verbal communication.

The chief focus of this study is on Leonardo the individual. As a corollary, an attempt has been made to see where these ideas stand in relation to a European context. In a number of cases it has been possible to trace how his rough ideas are taken up by thinkers in the North there to be developed only later to return to Italy in a more mature form.

This points to a radically different picture of the Renaissance as a highly creative cultural period. The Renaissance was not just a bright idea of the Italians that gradually spread to a dark North. It was a European phenomenon, possible only because ideas were being shared, explored, developed by very different kinds of minds.

3) Volume Two

Complementing these studies is a second volume with the provisional title: *Continuity and Discovery in Optics andAstronomy* (enclosure 2). Whereas the first volume offers a survey of Leonardo's philosophy of science in general, this second volume provides a detailed examination of the scope and limits of Leonardo's scientific method with respect to a specific branch of physics. Volume two is divided into five parts.

II. Part 1: Historical Context

A survey is given of the optical tradition from Euclid to Kepler. It is noted that in Antiquity and throughout the Middle Ages the term "image" was treated equivocally such that mental images and physical images were not distinguished. It is claimed that Leonardo's optical studies introduce a basic change in approach. He adopts traditional verbal similes, takes them literally and translates them into visual problems which can then be experimentally verified. As a result problems of optics which had been subjects for philosophical debate become questions of physics. The way is thus prepared for Kepler's later distinction between those images which can be quantitatively measured (*pictura rerum*) and those which are purely subjective (*imagines rerum*).

Leonardo's concept of percussion is studied. It is shown how this fits into Leonardo's system of the four powers by means of which he set out to explain all physical phenomena.

II: Part 2: Physics of Light and Shade

His basic definitions and concepts of light and shade are examined. This leads to a reconstruction of the *Seven Books of Light and Shade* as outlined on *CA 250* (c. 1492). It is shown that his camera obscure studies complement these writings on light and shade. It is established that his experimental method was much more systematic than has hitherto been suspected.

II: Part 3: The Eye and Vision

Leonardo's notes concerning individual parts of the eye such as eyelids, cornea, crystalline lens and optic nerves are examined. His theories concerning their physiology and the visual process as a whole are analysed. His notes on appearance and illusion are considered and their relation to Euclid's *Optics* is assessed. This leads to a consideration of his notes concerning optimal and minimal conditions of vision.

II: Part 4: Astronomy as Goal of Optics

This section opens with a survey of his writings on variable pupil size. It is claimed that this problem is central to his optical studies. Examination of an optical treatise within the *Manuscript F* confirms this and offers clues concerning the structure of the *Manuscript D.* These treatises in conjunction with the *Codex Arundel* provide an outline for the reconstruction of an astronomical treatise that he was preparing entitled Fourth Book: Of the Earth and its Waters. An analysis of the themes of this treature confirms that Leonardo's optical writings were intended as an introduction to his study of astronomy.

II: Part 5: Conclusions and Epilogue

Here attention is given to the consequences of Leonardo's methods of visualisation in optics for the progress of science generally. In the appendices his notes on optical instruments such as eyeglasses, telescopes, lens grinders; mirrors, plane, convex and concave and meteorology are examined.

In order to present this material a threefold approach is being developed. First there is a challenge of assessing the validity of Leonardo's claims from a modern viewpoint. How many marks would he have received on a modern physics test in optics? Second there is a question of reconstructing his ideas in a way such as he himself foresaw, had he had time. Third there is a problem of explaining why the notes have their present form. It is shown how a technical knowledge of his subject matter plus an understanding of his methods of organization by theme and analogy help reveal that his actual notebooks contain a far more methodical approach than has hitherto been assumed (cf. § 5-Cs below).

4) Volume Three
Throughout volumes one and two Leonardo's own statements have been cited in translation. The original Italien to all these folios will be provided in a concor-dance, which will also provide a complete series of cross-references to alternative systems of notation: e.q. in the *Windsor Anatomical Corpus* CV7r=W 19127r = K/P104r.

5) Six Stages of Development

These studies of perspective and optics have revealed that Leonardo's notebooks, which strike the untrained eye as chaotic are guided by an underlying method. This method becomes manifest once we analyse individual folios a) in terms of different modes of communication and b) various stages of completion.

Different modes of communication

Leonardo's notebooks can readily be classified in terms of three modes of communication. In many cases (A) he seeks to make his point primarily through verbal demonstrations/arguments. This leads to folios where columns of text dominate the sheet and diagrams are eventually relegated to the right-hand margin to serve as visual captions. Alternatively, (B) he endeavours to make his point with visual demonstrations/arguments in terms of a series of diagrams. A third possibility (C) is that he wishes to illustrate a given proposal in terms of a single technical drawing or illustration. These three modes of communication provide a framework for organizing his notes.

A) Verbal Demonstrations

For each made of communication six basic stages in the development of the notes can be identified. In the case of verbal demonstrations, for instance, a first stage involves no clear sheme (fig 1). Notes on diverse topics are scribbled with no apparent rhyme or reason. At this stage a folio serves as a scratch pad for jotting down ideas and alternatives.

At a second stage (fig 2) a folio is dominated by two or three topics. These may well remain disparate, but each topic is developed thematically.

At a third stage (fig 3) a single theme dominates a folio. In extreme cases such a folio may at first sight appear more chaotic than stage two. Even so, in terms of content, it is more coherent. At a fourth stage (fig 4) text dominates a folio and provides its basic structure in terms of one to four columns. Amidst these columns are scattered diagrams with no clear order. These columns become more carefully arranged at a fifth stage (fig 5) where diagrams are relegated to the right hand margin. At a sixth stage (fig 6), apart from further polish, information is added concerning the next folio.

Leonardo has three ways of doing this. Sometimes he simply numbers his folio. At other times as in the *Ms. F*, having numbered the folios, he abandons the expected order and gives instructions where to turn at the bottom of each given sheet. Alternatively he numbers the marginal diagrams and thereby establishes the sequence, as in *Ms Forster I.*

B) Visual Demonstrations/Arguments

In cases where he is developing visual arguments the first three stages often follow the pattern outlined above. At a fourth stage (fig 7) a single theme dominates the figures. They are organized in columns but the method underlying their arrangement is not manifest. At a fifth stage (fig 8) this arrangement becomes clear and a systematic development can be traced. At a sixth stage (fig 9) this systematic sequence is numbered.

C) Proposals and Technical Drawings

In the development of technical drawings and illustrations the first three stages again follow the usual pattern. At a fourth stage (fig 10) a single theme such as military weapons or hydraulics emerges in which various drafts concerning one or more devices are apparent. At a fifth stage (fig 11) advanced drafts of two or three devices dominate the folio. At a sixth stage (fig 12) a single illustration dominates a folio. A similar development applies to his drafts for paintings.

6) Systematic Elements

Once individuai folios have been arranged in these terms further possibilities of systematic arrangment come to light. In the case of A) verbal demonstrations, for instance, not only various drafts for arguments can be arranged chronologically, but also his preparatory sketches for what become marginal visual captions. In the case of B) visual demonstrations, these possibilities of systematic arrangement are greater. Nere it is possible to show how his preliminary sketches involving individual elements lead gradually to systematic demonstrations (figs 13-18).

More dramatic still are the possibilities in the case of C) visual proposals and technical drawings. Here it is possible to trace how a rough sketch gradually evolves into a complex finished illustration (figs 19-21).

Once Leonardo is approached in these very concrete terms it becomes desireable to extend this approach to contemporary artist-engineers such as Taccola and Francesco di Giorgio Martini. What then emerges is a more realistic picture of what Leonardo adapts and sometimes simply copies (figs 22-24, 25-27).

In the long term one would wish to apply this approach also a) to his earlier sources such as Euclid or Aristarchus and b) to his successors in the 16th and 17th centuries. Such a fundamental reorganisation of all Leonardo's notes could begin as a four-year project and be finished with a long term plan in six stages and four phases.

7. A Four-Year Project

At the outset (Phase A) one would concentrate strictly on Leonardo. The project would be organised in three stages: 1) collection of photographs of all his notebooks; 2) copies of same arranged thematically under flight of birds, hydraulics etc. and in six stages of completion; 3) provisional systematic arrangement of individual elements.

If the necessary help were available a next step (Phase B) would be possible within this period, namely, to extend the three stage approach to Leonardo's contemporary sources (c. 100 manuscripts).

8. A Long Term Plan

Once Leonardo's demonstrations have been arranged it will be possible at a 4th stage to make comprehensive experimental reconstructions of his work in statics, hydraulics etc. At a university many of these could be carried out by students with scientific training enrolled in a course on the history of science.

At a 5th stage one would supervise historical studies of individual problems. At a university some of these could begin as term papers and emerge as articles. More complex cases would lead to M.A. and Ph.D. theses and where necessary to independent research projects. At a 6th stage one would supervise similar studies with respect to Leonardo's successors.

Once Leonardo's contemporary sources (Phase B) have been systematically arranged in terms of individual elements, this approach can be extended to include his chief ancient (figs 28-31) and mediaeval sources (Phase C) and eventually also (Phase D) his chief successors in the 16th (Porta, Besson, Ramelli), 17th (e.q. encyclopaedists such as Ens, Bettinï, Kircher, Schott and De Chales) and the 18th centuries (e.g. Wolff, Karsten, d'Alembert) (cf. Chart 1).

9) Significance

Such a project has basic implications not only for Leonardo scholarship in particular but equally for the difficult questions of the rise of early modern science as a whole and the relations between science and art. Each of these will be considered in turn.

Leonardo’s Scholarship

A systematic approach such as that outlined above will bring to light many unknown aspects of Leonardo's method. It will permit us to trace in concrete terms how he builds on and transforms his sources (cf. figs 22-27) and make it possible to see how he develops a new idea step by step, starting with a rough scribble and ending in s masterful drawing (fig. 32-37).

We shall also be in a position to estimate in quantitative terms how much energy he devoted to specific fields; and even trace to what extent he developed his various interests.

Rise of Modern Science

At the same time this approach will offer fresh insights concerning the rise of early modern science. Most historians today would accept that the ideas of Galileo, Descartes, Huygens and Newton represent the cornerstones of modern science and that these cornerstones owe something to earlier discussions. A claim for continuity with ancient and mediaeval sources introduces the problem, however, of explaining what it was that changed.

A chief reason why existing approaches have been unsuccessful in answering this question is because their positivistic bias leads them to focus their energies on determining the first mention of a given discovery, invention or technique, with little interest in collecting all mentions of these discoveries. Because they focus on changes in isolation, such approaches cannot hope to answer elusive questions of change in continuity.

The proposed encyclopaedia of illustrations/descriptions of individual discoveries, inventions and techniques prompted by the Leonardo studies promises fresh solutions to this problem. For these lists will enable one to trace changes in the solving of a particular problem over centuries, will reveal how isolated experiments in the mediaeval period lead to systematic series of experiments in Leonardo (figs 38-43) which then become formulated in algebraic terms with Galileo.

Because such an encyclopaedia will also permit one to study the development of scientific concepts such as experiment and quantification in terms of specific technological problems a new understanding of relationships between science and technology will emerge.

The encyclopaedia will also provide a much more sophisticated understanding of the rise of experiment. Today many historians still ask when the first experiment occured. In future it will be possible to study temporal and other discrepancies in the development of experimental and quantitative techniques in individual branches of science. An understanding will emerge of differences in the early stages of optics, statics, kinematics, hydraulics and so on.

With further study it will, moreover, be possible to trace how the common factors between these branches slowly came into focus and eventually emerged as an integrated body of mathematical sciences. In this task the systematic catalogue at Góttingen could prove an invaluable aid. In short this new approach to Leonardo, in its extended form, promises a fundamental enrichment in our understanding of the origins of modern science.

Science and Art

The development of science can be seen as a shift in the criteria for what constitutes proof and authority. In e pre-scientific approach old men, old books, appeals to supernatural connections can all constitute proof and authority. In a scientific approach the criteria for proof are radically reduced in number. Any verbal claim or hypothesis must be experimentally and quantitatively verified.

This scientific verification is effectively a process of translating all verbal claims of authority into visual claims -- these being the only claims which are precisely measurable and repeatable. Hence the history of science is ultimately a history of visualisation. In the nineteenth century various individuals intuitively recognized this link between science and visualisation, and hence they distinguished clearly between *Kunstwissenschaft* and *Kunstgeschichte.* But in our century this distinction has faded. There are still no English, French or Italian equivalents for these German terms.

All too often visualisation is associated strictly with art which is approached as if it were in opposition to science, it being assumed that art is qualitative and subjective while science is quantitative and objective. For this reason, notwithstanding florid rhetoric about general links between science and art, the visual dimensions of science have effectively been ignored.

The historical encyclopaedia of scientific images prompted by the Leonardo studies will thus bring into focus a basic source of human knowledge that has hitherto been neglected. At the same time it will prepare the way for a future synthesis.

At present there are various collections such as the Princeton Index, I Tatti, the De Witt Collection and the Marburg Index which are collecting primarily paintings and frescoes with a focus on their aesthetic and iconographic elements. These paintings also contain a great deal of scientific information: Renaissance representations of the *Tower of Babel* are, for instance, filled with information concerning 15th and 16th century building practice.

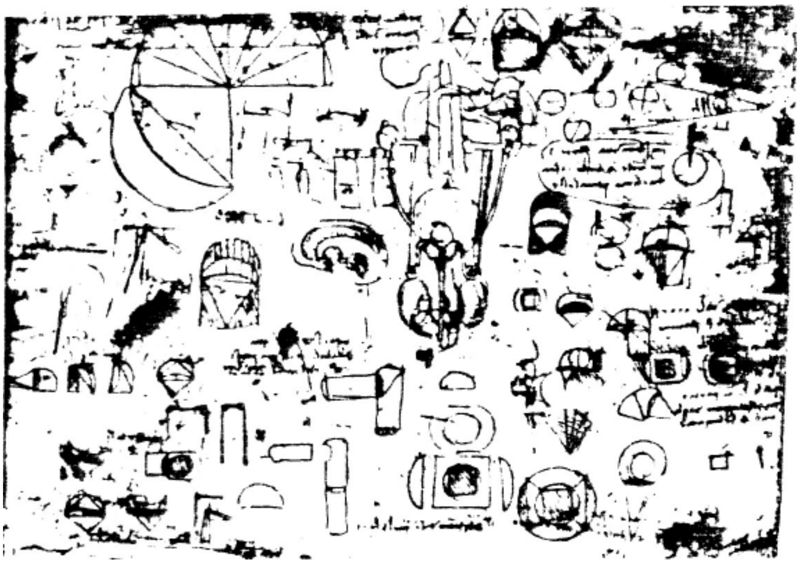
Once an encyclopaedia of scientific images has been developed, then information from paintings, frescoes, Books of Hours and other artistic sources can be integrated and the relative value thereof assessed. The now largely rhetorical question of links between science and art could then be approached in concrete terms.

10) Methods of Recording and Display

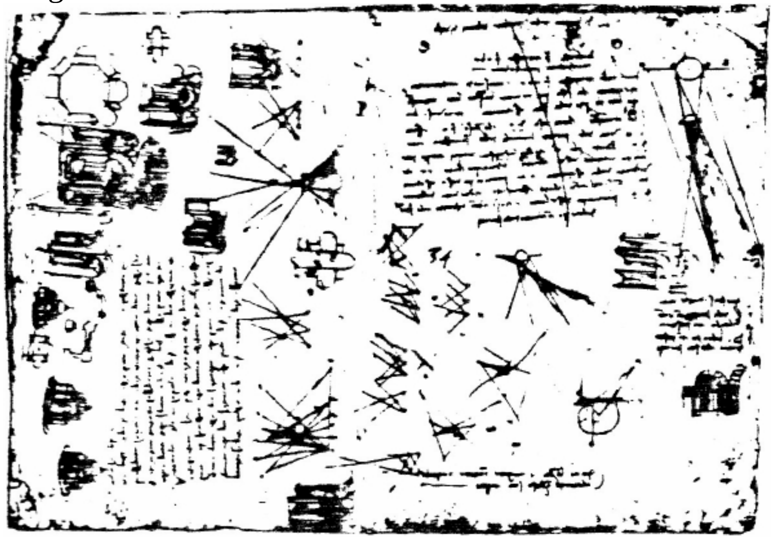
At the outset the project would involve the use of photographs from facsimiles of the Leonardo manuscripts and those of his contemporaries. From these, photocopies could be made for purposes of cataloguing individual items. The resulting catalogues of images could then be published in microfiche form, perhaps as a special branch of the Photo-Marburg project.In future it will be useful to have these catalogues of images recorded such that they can be recalled on a video - and/or television screen. Computer aided retrieval systems could subsequently add dramatic new possibilities to the project. Indeed what began modestly as an encyclopaedia of the images of a universal man might lead, one day, to a universal encyclopaedia of knowledge.

	Phase A	Phase B	Phase C	Phase D
	Leonardo	Contemporaries	Sources	Effects
Stage 1	Photographs of Manuscripts	“ “	“ “	“ “
Stage 2	Arrangement of folios in six stages of completion	“ “	“ “	“ “
Stage 3	Arrangement of individual elements	“ “	“ “	“ “
Stage 4	Reconstructions of claims	“ “	“ “	“ “
Stage 5	Sources	“ “	“ “	“ “
Stage 6	Effects	“ “	“ “	“ “

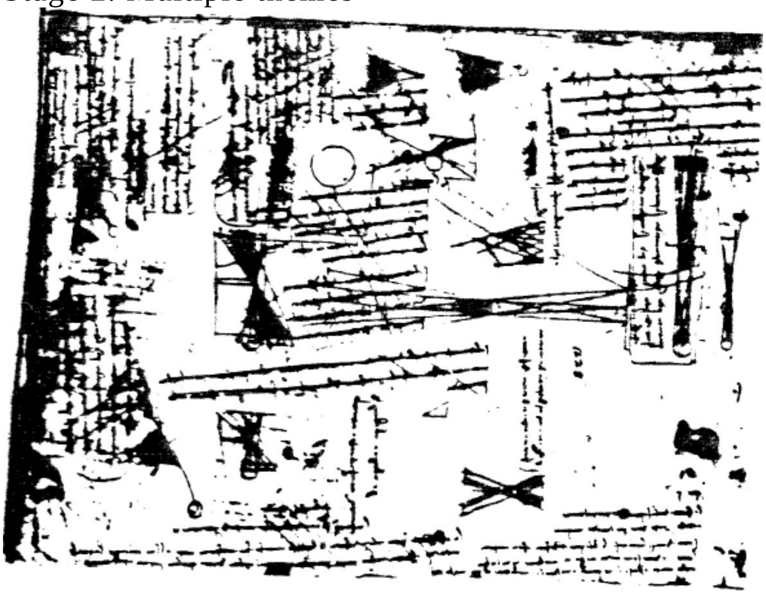
Chart 1 . Outline of Project in terms of six stages and four phases.



Stage 1. No clear theme.

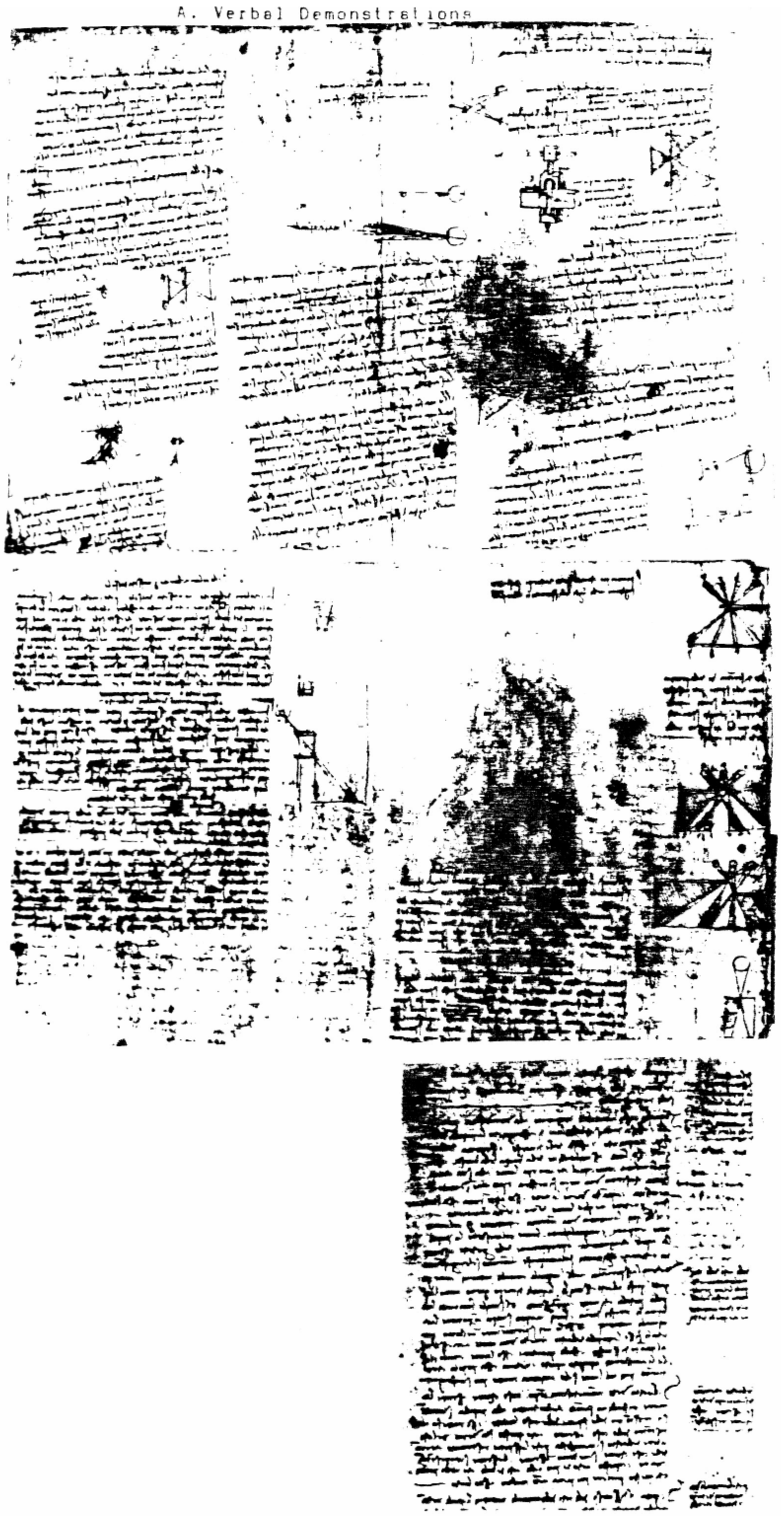


Stage 2. Multiple themes

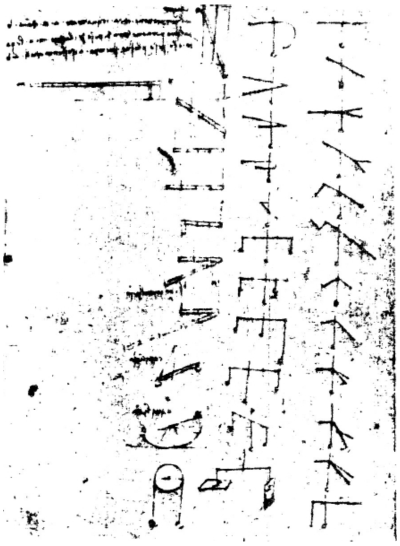


Stage 3 Single theme

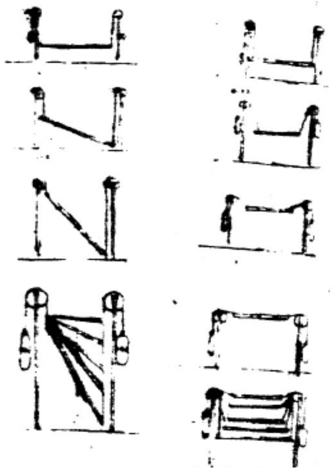
Figures. 1-3. Early stages in the organisation of Leonardo's notes.



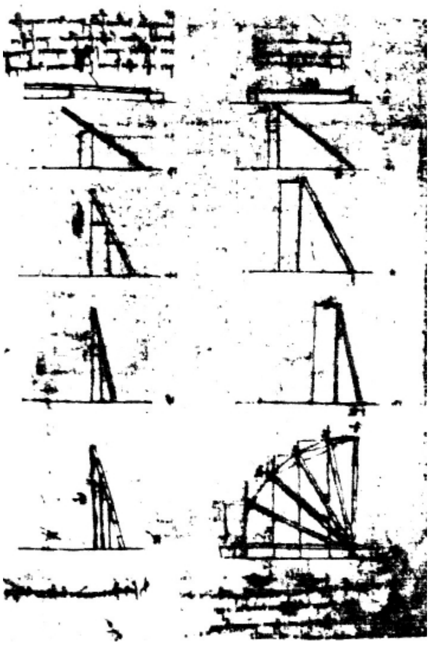
Figs. 4-6. Three further stages in the organisation of Leonardo's, Figures 4-6.
4A Single theme, columns random diagrams;
4B Single theme, columns, marginal diagrams/notes
4C Single them, columns ordered marginal notes, diagrams.



Stage 4B Single theme: Columns, no clear development

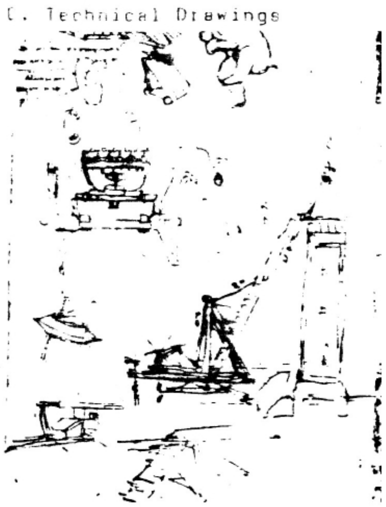


Stage 5B Single theme columns systematic development.

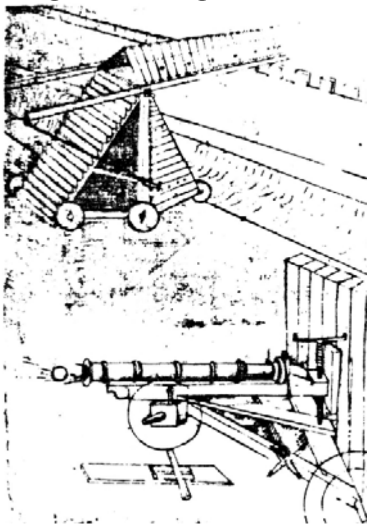


Stage 6B Single theme columns numbered systematic development.

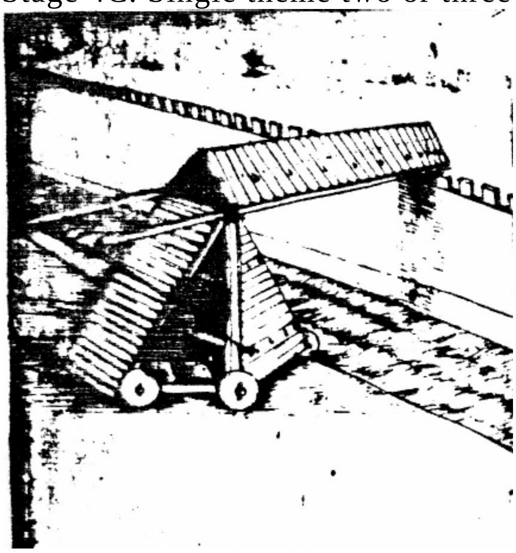
Figs. 7-9. Three further stages in the organisation of Leonardo's visual demonstrations.



Stage 4C. Single theme various elements

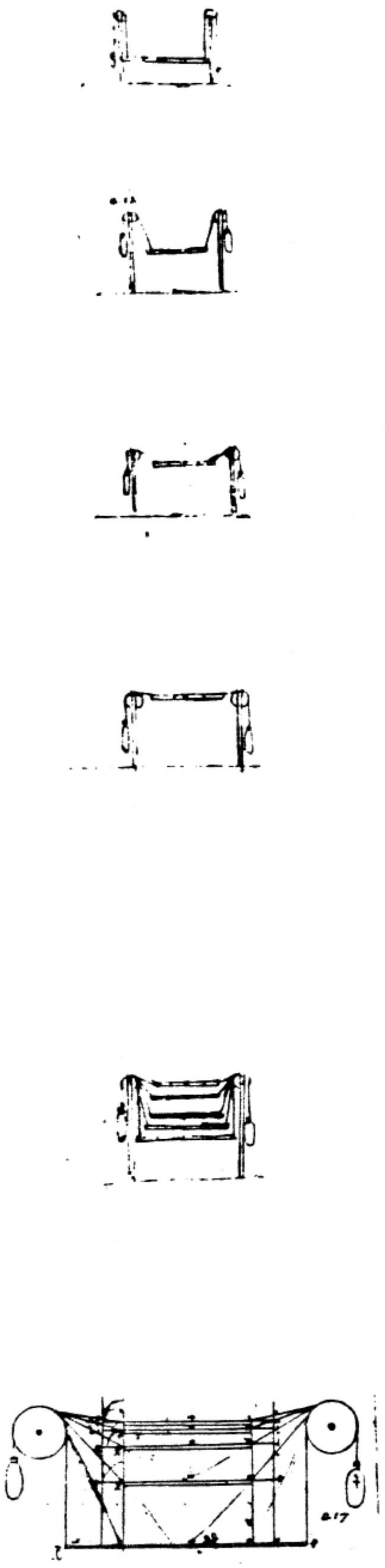


Stage 4C. Single theme two or three elements

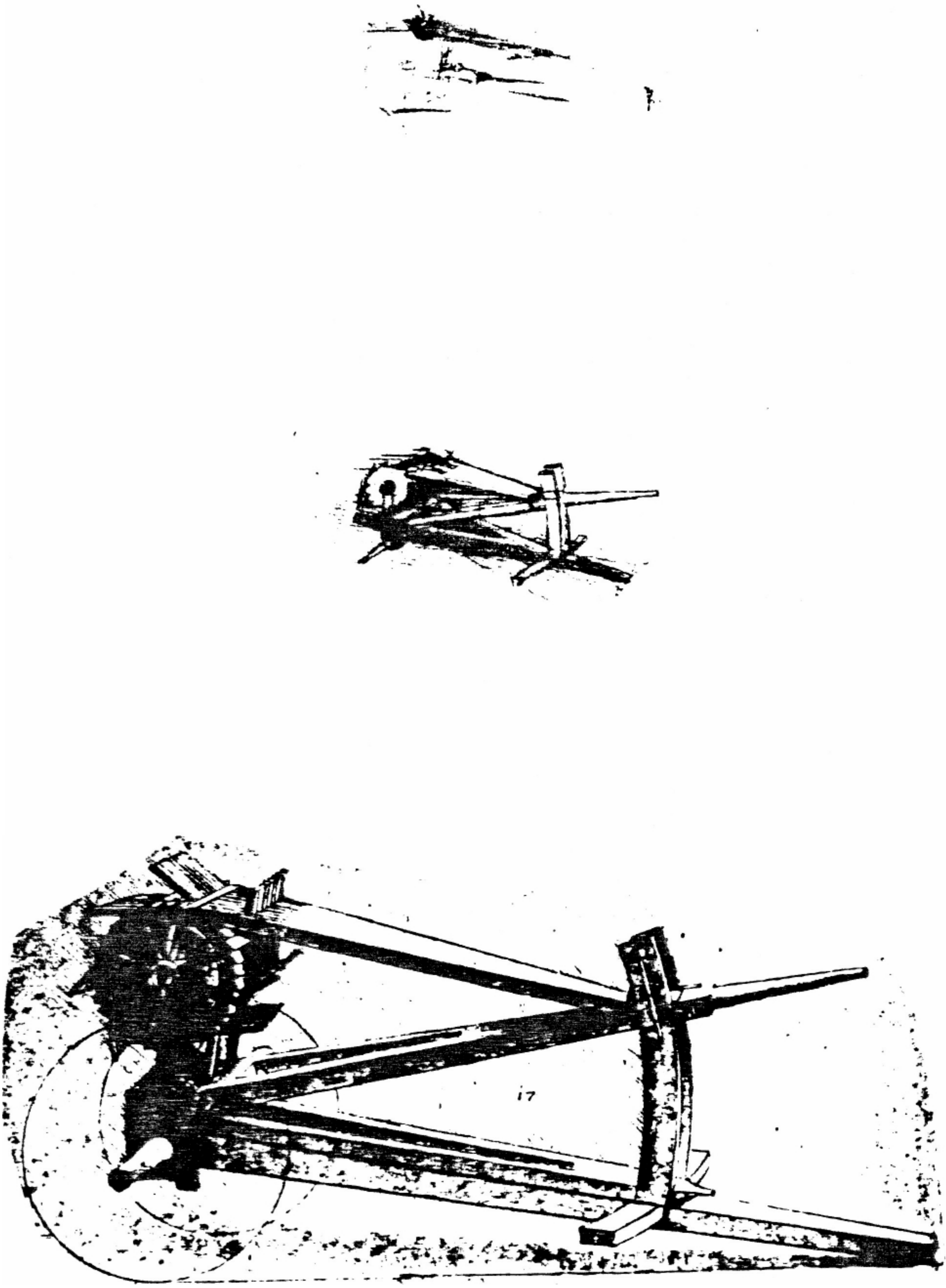


Stage 4C. Single theme single diagram

Figs . 10-12. Three further stages in the case of a technical drawing.



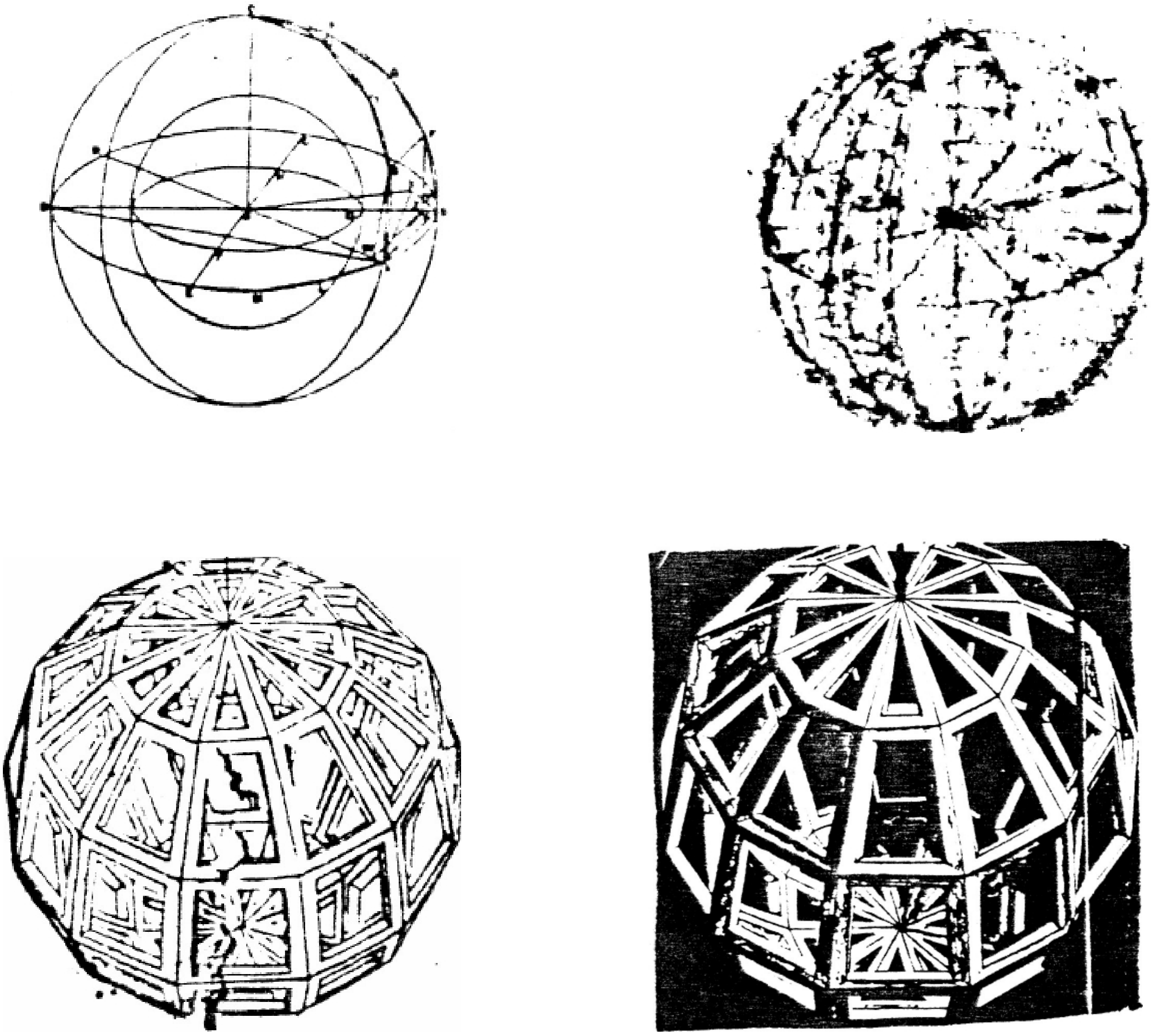
Figures 13-18. Steps in the development of a systematic demonstration. First, individual cases are studied (13-18). These are then summarized (17) and then redrawn more formally (1B).



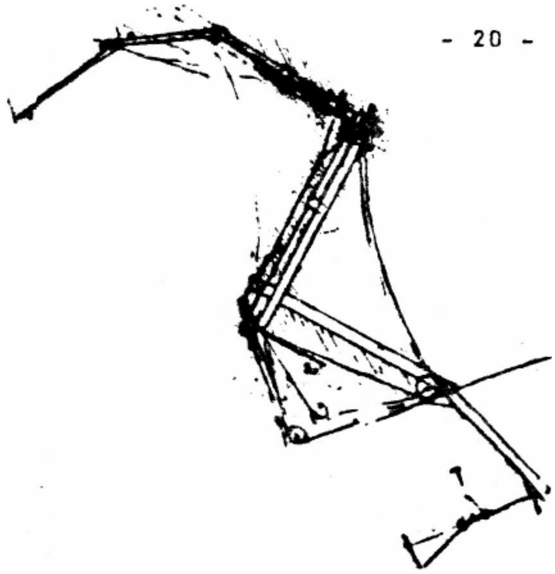
Figs. 19-21. Three stages in the development of a technical drawing.

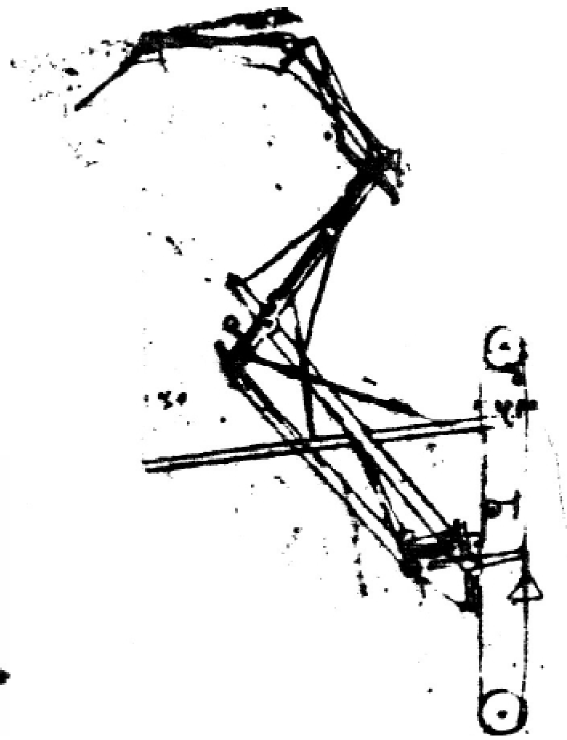
Figures. 22-24. The examples of Francesco dí Giorgio Martini (figures 22-23) become the basis of Leonardo's "invention" of the life jacket.

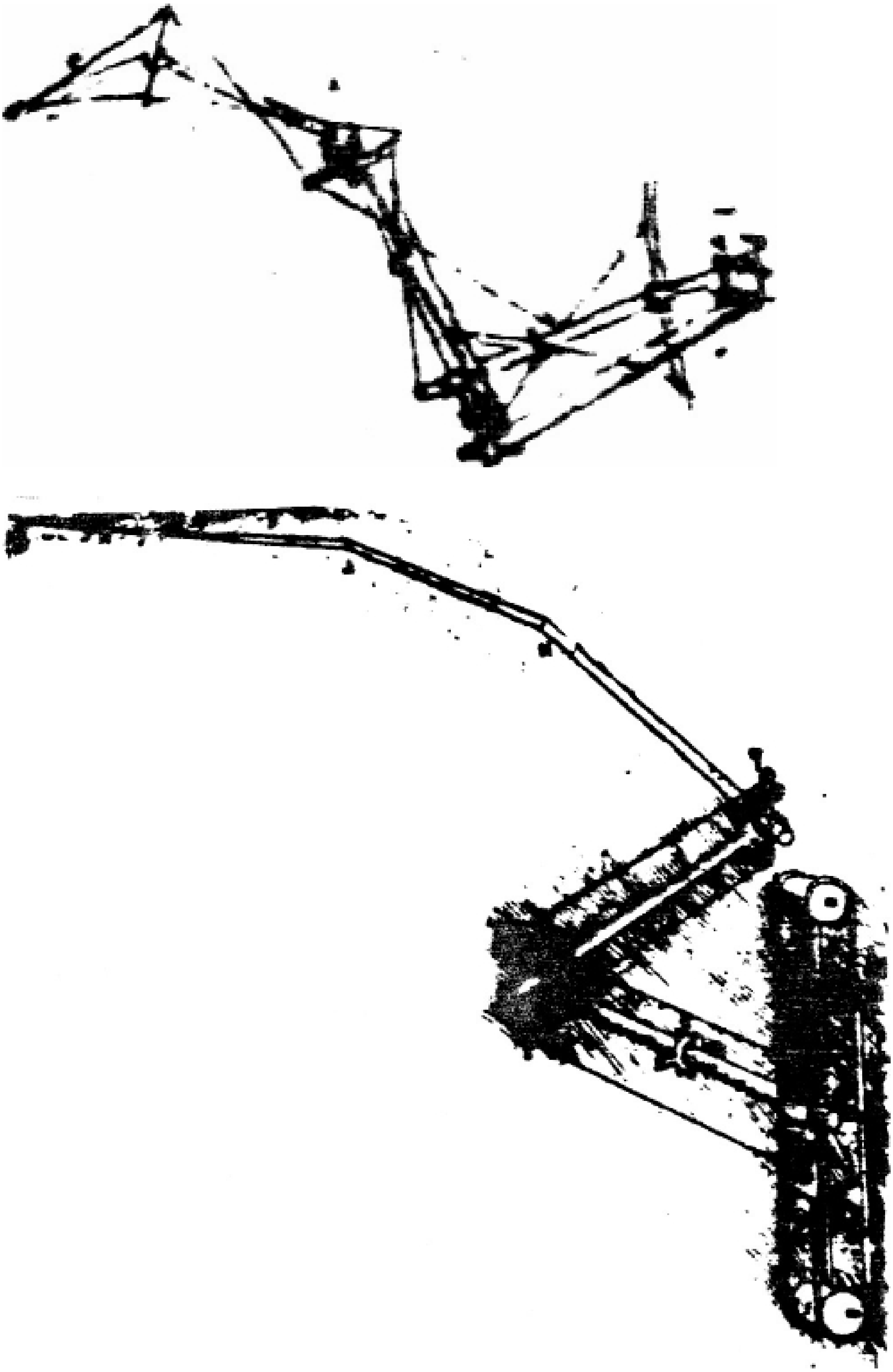
Figures. 25-27. Francesco di Giorgia'a drawing of a snorkel (25) is the starting point for Leonardo's drawings (26-27).



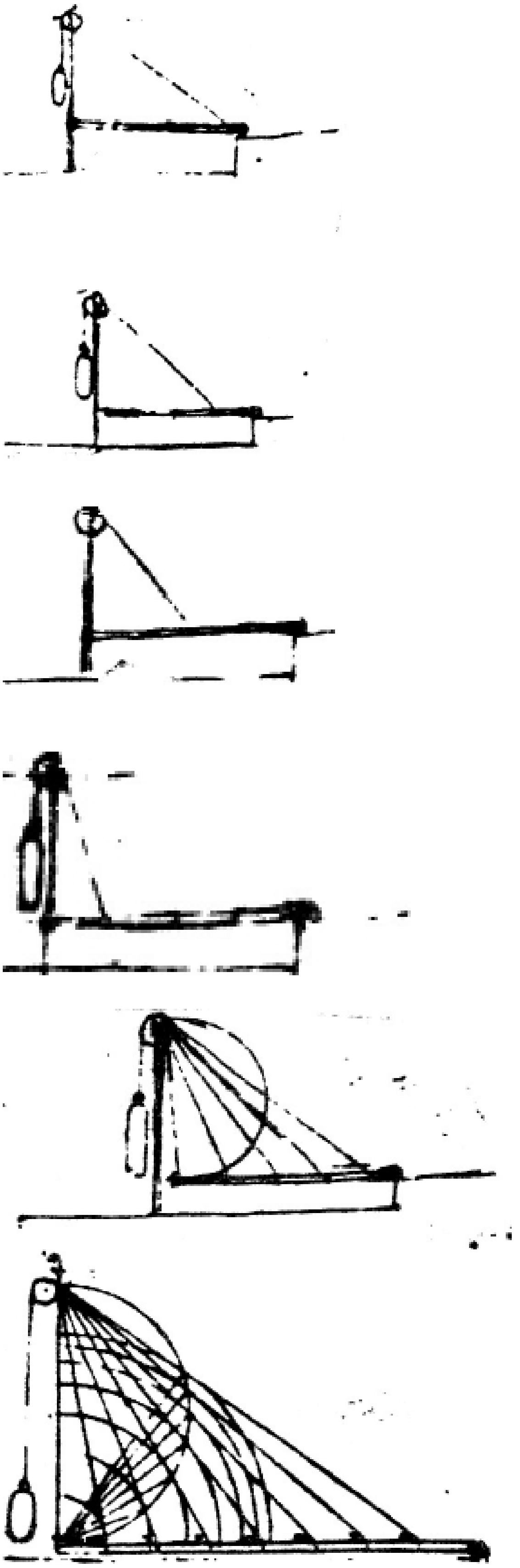
Figures. 28-31. A diagram in Euclid's *Elements*(28) serves as starting point for Leonardo's drawings of a 72 aided polygon.







Figs. 32-37. Six steps in the development of a mechanical wing.



Figs. 38-43. Isolated experiments were common in the Middle Ages. What is new with Leonardo is that he makes hundreds of systematic experiments such as the above.