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LEONARDO DA VINCI INTERDISCIPLINARITY

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Abstract

Considering that the word "interdisciplinary" has stood out in the contemporary cultural and academic studies, approaching the involvement and the dialogue between different disciplines for mutual enrichment, this article shows the reflections on works of the genius Leonardo Da Vinci, addressing relevant aspects of his multi, interdisciplinary and technical studies about flying machines and their concepts applied in the current context of the aeronautical world. Its content seeks to establish interdisciplinary relationships throughout the history of mankind. The evolution of knowledge that has presented a great variation of speed and amplitude, being able to consider the present moment as an important historical landmark, especially with regard to interdisciplinary studies and their importance. The purpose of this article is to demonstrate the connection between engineering, humanity, art, and Da Vinci flight concepts.

Introduction

The present work deals with the interdisciplinary study relationships established between Leonardo da Vinci flight engineering studies and the interconnection between other fields of science. Its content seeks to demonstrate the connections between engineering, art, humanity, and Da Vinci flight concepts. It is organized into three sections. Initially, a brief history of Leonardo`s Da Vinci life. Then, contextualizing his works on the human flight possibility. He produced more than 35,000 words and 500 sketches about the flight of birds and flying machines, including a helicopter. In 1505/1506, Leonardo produced a small codex entirely called "*Volo degli uccelli*" or "Flight of the Birds"[1]. Among the many subjects Leonardo studied, the human`s mechanical flight possibilities held particular importance for the future. Finally, a correlation with the current theories of aerodynamics and the so-called "Science of the Winds" studied by Leonardo for the development of his projects, besides the analysis of the various disciplines mentioned in his works, especially those related to the engineering of the flying machine. In this context, the development of this descriptive research is justified, being characterized by speculative hypotheses that do not specify the causal relations. This approach aims to highlight the strong interdisciplinary exercised by the subject in this investigation. Regarding the procedures, the research is bibliographical, considering Leonardo´s works known by renowned authors, including the Da Vinci writings. Finally, the considerations will be made with the exposition results, as well as reinforcement of the importance of the interdisciplinary theme, and the relation that the systems or disciplines relate to.

Leonardo Da Vinci´s life

Leonardo da Vinci was born in Anchiano near the Tuscan, county of Vinci, Florence, province of Tuscany, Italy in 1452 [2]. An illegitimate son of Piero DaVinci and Caterina. The father was a notary and the mother was a peasant, Leonardo did not have a relevant education for the time, being instructed only by his grandfather. Most of the authorities refer to their work as Leonardo and not Vinci. It is presumed that he did not use his father's name because of the illegitimate state. At the age of 14, he was sent by his father to Florence to an arts school where he learned painting, sculpture, and the crafts in general, as well as studies in optics, music, and poetry. He worked as an apprentice to painter and sculptor Andrea Verrocchio, one of the most famous artisans in Florence. He developed in diverse subjects of the time and was an extremely fast learner, and different from his companions of the same age. During this period that his genius traits began to appear. In a study conducted in 1926, his IQ was estimated at about 180. Other more precise sources mention values between 220 and 250 [3]. The difference of his ideas, the quality of his drawings impressed his masters and, at the age of 20, he was admitted as a member of the Corporation of St. Luke, the Florentine artists.

Leonardo's professional growth takes place from his first autonomous orders reception, which only happened in 1478, with the paintings of the Chapel of St. Bernard in the Signoria of Florence [3]. During the period of formation in Florence, his recognition was increasing, as also were the number of his enmities and the tension of political life in the city that threatened his aspirations of prestige and glory. He moved to Milan in 1482, at the age of 30, where he opened up vast fields and making him known in a much larger sphere than in Florence. In fact, introducing himself to the Milan court, first as a musician and later as an engineer. In Milan, he lived with the plague of power as he had never imagined before, he meets mathematics and, in 1490, adopts his assistant, Salai, who stayed with Leonardo all his life.

Still, according to Carreira [3], Leonardo lived in Milan becoming a Sforza family engineer when he began to develop military weapons and hydraulic studies of the city channels. Although devoid of the fortune that, he never got to possess, at the age of 30, besides working for Duke Ludovico Sforza designed and painted scenarios for parties and local events.

Da Vinci was versatile and acted in various fields of human knowledge, and he is currently referred to as one of the greatest known geniuses on planet earth. A man of great culture. Based on the various definitions of the English philosopher Terry Eagleton [4], culture suggests a correlation between good manners and ethical behavior, or "as a synonym for civilization. The culture was part of the general spirit of the Enlightenment with its cult of progressive and secular self-development "[4]. Culture can also mean learning and the arts, activities confined to a small proportion of men and women. It may also, in another context, "mean a body of art and intellectual works of recognized value, as well as the institutions that produce, disseminate, and regulate them"[4]. Leonardo had all these attributes.

As a request for Sforza to decorate one of the walls of the convent of Santa Maria Delle Grazie to bury his family, in 1495 he began painting the famous "The Last Supper" which, as described in the Bible, would be the last meal of Jesus Christ with his 12 apostles before his death and resurrection. In 1499, Leonardo began painting "Mona Lisa".

In the process of decay, Leonardo returns to Florence to render his services to the Borgias, performing like never before as an engineer. And through Caesar Borgia, Leonardo had contact with Machiavelli, who, liked him, also works for the Florentine Republic in the wars against Pisa. At the same time, he meets Michelangelo, the only artist who will match him in fame and genius still alive.

Due to an invitation from King Louis XII, he returned to Milan between 1506 and 1513. Then Leonardo spent another ten years, with some short stays in Parma, Rome, Bologna, and Florence. Finally, he returned to Gallia, where he settled in the Château de Ambroise, where he was going to amuse the French kings, pass on his legate to his assistant and friend Melzi, and die two years later [3]. Francesco Melzi transferred all the treasures he inherited to Vapriod’Adda, just outside Milan, where he guarded them carefully. After Melzi’s death in 1570, all the materials passed down to his heirs and then Leonardo’s manuscripts passed from hand to hand and place to place [1].

Many of his works were lost, destroyed or unfinished. Only about 16 Leonardo`s paints are known and have indisputable authenticity. Author of a great artistic production, something around 13 thousand pages written. It is estimated that at present, only about 600 drawings and manuscripts of his authorship are known and that represents perhaps a third of his vast work.

The interdisciplinary variation

Leonardo da Vinci painted, studied anatomy, physics, botany, geology, and mathematics alone, and several times used all this knowledge simultaneously in his projects, which would prove the use of the current concepts of interdisciplinary. As Raynaut points out, "The idea of interdisciplinary converges at times into an intellectual dream: that of restoring the oneness of knowledge; to arrive at new forms of knowledge that embrace and reconcile the multiple faces of knowledge" [5].

Many people found Leonardo unreliable as a painter. He was desperate to create what he called the "work of fame," something that would make him famous for posterity. He finally gained fame with "The Last Supper." For Leonardo, the painting was the royalty of the arts, which provided greater emotions and feelings. The painting "The Last Supper" is a Renaissance masterpiece that has been praised, studied and copied for more than 500 years.

Da Vinci had a great curiosity and fertile mind for science and technology. He wrote several documents, thousands of writings, pages and drawings called codices, as well as manuscripts. Leonardo da Vinci has always been very "beyond" his time, which, according to Dr. Homi Bhabha, the professor at Harvard University: "*Beyond* means spatial distance, marks a progress, promises the future, yet our suggestions to overcome the barrier or the limit; the very act of going beyond; are unrecognizable, unrepresentative, without a return to the "present" which, in the imaginary of spatial distance; living somehow beyond the frontier of our times; highlights the social, temporal differences that interrupt our conspiratorial notion of cultural contemporaneity" [6]. Da Vinci was then referred to as one of the great geniuses of history. He acted with a transversal, interdisciplinary, flexible thinking and a deep assimilation of literature.

According to Peter Jakab among the many subjects studied by Leonardo, the possibility of human flight was particularly fascinating. "He produced more than 35,000 words and 500 sketches dealing with flying machines, the nature of air, and bird flight" [2], including a helicopter model. Leonardo produced a small codex entirely on the subject in 1505/1506, the *Codice "Volo degli uccelli"* or *"Flight of the Birds"* Codex [7]. The entire Codex revolves around the idea and the construction of a flight machine like a bird which Leonardo decided to observe and imitate.

Leonardo's contact with flight happened as a child when he was seen watching birds of prey in the fields near Florence. Leonardo's first bird drawings were around 1470 after he moved to Florence to work as an independent artist.

Leonardo's writings are mainly in cursive letters of mirror image. The reason may have been more of a practical convenience than for reasons of secrecy, as is often suggested. Since Leonardo was left-handed, it was probably easier for him to write from right to left. According to the professor, P. G. Aaeron "all of Leonardo's errors of language and computation can be viewed as manifestations of a weakness in the sequential processing of information, and his great achievements in art and science can be seen as the result of an overcompensating holistic-gestalt mode of thinking" [8].

It was Leonardo's intention to write an entire treatise on the flight. The Flight Codex was probably packaged in preparation for one of the chapters of this treatise. This explains why it was written with such an unusual degree of organization, almost "paginated" according to a graphics project. According to the most reliable thesis, Leonardo wrote the Codex on Flight in reverse order, starting from page 18 to get to page 1. The text runs from the bottom of the right-hand page [5].

According to Fritjof Capra [9], Leonardo's interest in man's flight was based on the study of the legend of the flight of Daedalus and Icarus, who according to Greek mythology escaped from Crete using wings. To extract them from prison, Daedalus built wings with feathers that he attached to their bodies with wax. Despite his father's warnings not to fly too high, Icarus got carried away the thrill of flying and got too close to the sun; the heat melted the wax, causing him to dive to his death at sea. Tradition holds it as an example of what happens to those who try to perform actions beyond their capacity and means. The image of Dedalus (Fig.1) with its wings at one of the carved panels that decorate the lower part of Giotto's bell tower in Florence may have been both an inspiration and a challenge for the development of a human flying machine [9]. At the court of Milan, where he designed weapons, military machines, and fortifications, including a tank and a submarine, Leonardo focused on military tactics, which led him to the idea of aerial reconnaissance.

Fig. 1. Campanile di Giotto, Dedalo

Considered modern science father, once involved with the idea of a flying machine, its development became an obsession. His first studies for the flapping-wing flying machines dated to the Milanese period of 1487-1490 as well as the reference to a helicopter model.

As his scientific mind matured, Leonardo began to elaborate a more theoretical approach to this challenge, which involved numerous disciplines, from aerodynamics to human anatomy, from bird anatomy to mechanical engineering. Leonardo Da Vinci was possibly one of the precursors of individual interdisciplinarity, as described by Claude Raynaut on the "... orchestra man capable of manipulating and integrating concepts and methods coming from different disciplines. The Leonardo da Vinci are few, cannot constitute the standard of academic formation"[10]. Leonardo practiced interdisciplinarity by necessity, to open new theories, questions and solutions confirming the affirmation of Raynaut: "Interdisciplinarity can never be imposed from the outside. It necessarily comes from the living consciousness within each of the limits of their own discipline and the challenges to be overcome to respond to the complexity of the world today" [10].

Most of Leonardo's aeronautical projects were similar to flying birds, that is, machines that used only wings to generate support and propulsion, where using the arms and legs, with mechanisms designed with levers, the pilot should achieve the lift and propulsion. Leonardo concluded that flying like a bird would require more than a pair of well-crafted wings. He would need to understand the subtle details that ensure the birds could flight in the air and be able to transfer knowledge of these principles to the design of a flying machine. Fig. 2

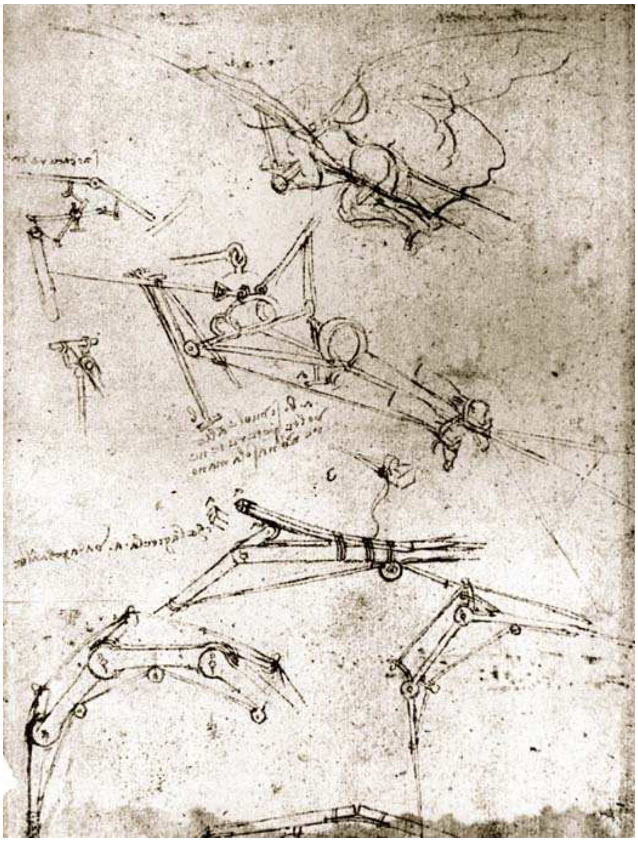

Fig. 2 Flying Machines 1490

The drawing is seen in Fig. 3 is, along with other similarities of the same period (contained in Manuscript B and Codex Atlanticus), which was the best Leonardo produced in the field of flying machine designs. One of Leonardo's greatest assets was his ability to deal with three-dimensional space. The board on which the pilot lies and the two pedals that operate the wing movement are clearly visible. The pilot's hands and arms are used to maintain balance and change course, much like a modern hang glider [1].

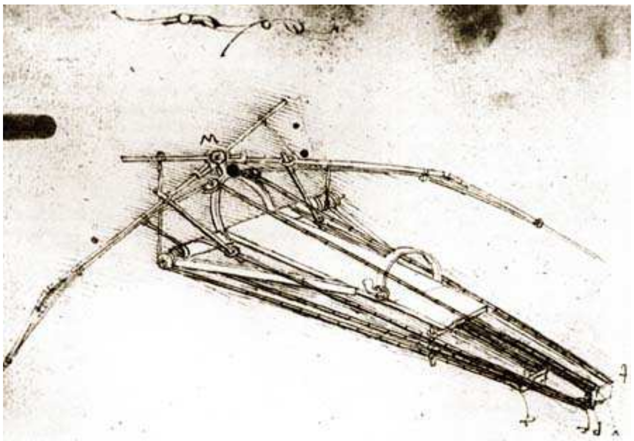

Fig 3 Flying machine, Ms. B. folio 74v

According to Zanon [1], in 1505, was the year when Leonardo came to a turning-point in his attempts to solve the problem of artificial flight. He proceeded to base himself on the gliding flight of certain birds of prey. Thus emerged a simpler aircraft, though more complex in terms of its pilotage, since it's certainly not a real "glider" and least of all, a hang glider. The machine featured adjustable wings that presume to simulate the slow maneuvers of raptors as they circle majestically at high altitudes, preparing to dive upon their prey. At the same time, he wrote in less than twenty pages of notes and drawings, the Flying Birds Codex [7], which describes a number of initial observations and concepts for the airplane development, centuries before any real progress in the development of a flying machine.

The Flight Codex is not an intuitive or easily understandable manuscript and is so difficult to interpret. In the view of the aeronautical engineer John Anderson, "Leonardo's aerodynamic concepts were strikingly advanced and would constitute a quantum leap in the aerodynamics of the time if they had been widely known" [11]. He studied the water flow escaping from a tank at different heights and diameters, proving Bernoulli's famous theorem 250 years before his proposition. Currently studied in engineering, in the matter Fluid Mechanics, it was applied by Leonardo to explain the forces involved in the flight of the birds' wings, in a study called "Wind Science" as Capra said: "In order to create the true science of the birds move in the air, he later wrote, summarizing more than thirty years of research, *it is necessary first to create the science of the winds, which we will demonstrate on the basis of the water movements*"[9]. In this passage, Leonardo affirms not only that the science of flight must be based on solid aerodynamics "science of the winds", but also that air flows can be compared to running water, both described by the same discipline: fluid mechanics, as we would say today [9].

The Bernoulli's well-known theorem demonstrated at the eighteenth-century by the Swiss mathematician Daniel Bernoulli states that by increasing the flow velocity of a fluid, it causes a reduction in its static pressure and vice versa. This theorem is widely used in basic aerodynamics books, that is, it can be concluded that in the upper part of the airfoil, blade or wing, will have lower static pressure, due to the higher velocity, consequently a suction called the lift. If we consider the profile of a wing, according to Bernoulli, increasing the fluid velocity increases the dynamic pressure and decreases the static pressure in the upper part of the wing, resulting in an aerodynamic force that can be concentrated in a single point called the center of pressure.

Leonardo also demonstrates a simplistic understanding of the relationship between wing curvature, inclination, and its lift, the basic theory of modern aerodynamics, that is the efficiency of a wing depends on the profile´s design beyond the angle of attack. A profile with greater curvature will tend to generate more lift.

Zanon [1] wrote that, on folio 9 of the codex (Fig.4), the drawings, represent the highest point that Leonardo reached in his study of flight. What he writes in the first paragraph, perhaps unknowingly, gets close of all to the concepts of modern aeronautics. In this page, Leonardo didn't draw the whole profile but just the leading edge, that which corresponds to the *humerus* of a bird's wing. Here he observes how the wind flow divides into parts, forming two flows that act in different ways on the wing. A modern airplane fly due to the shape of the profile.

According to a principle formulated by Bernoulli, when air meets the wing leading edge, it divides into two flows, one above and one below, that must travel two routes with different lengths. The curved top of a wing creates a longer distance from front to back than the bottom. This causes the air on top to travel farther, and thus faster, to reach the back than the air underneath, creating a difference in pressure between the two surfaces. An increase in the airspeed produces a decrease in pressure. This difference of pressure is precisely what generates the lift force [1].

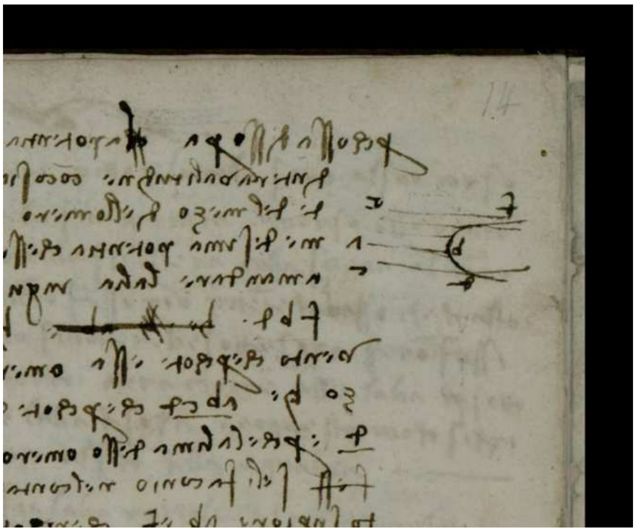

Fig. 4. Wind flow on the wing of the bird

Based on the flying bird´s observations, Leonardo also recognized that the impact of the air under the wings was a critical element to generate lift. According to engineer John Anderson, the detailed aerodynamics of flying bird is very complex and Leonardo could only understand it years later. "No doubt Leonardo was the first person to understand the mechanics of bird flight." [11]

According Zanon [1] the drawings on page 10 (Fig.5), portrays the bird´s flight trajectory, is one of most fascinating of the Codex. We can clearly see the circular route bird follows as it gains altitude. This is the same maneuver carried out by modern gliders using thermal currents. After observing birds soaring in the wind climbing into the sky without flapping their wings. Leonardo described the wind currents that sustain them in his codex. The main ones are the same that control the flight of modern gliders. When they find themselves inside currents, birds following circular paths, carrying out exactly the same maneuvers as gliders do when they encounter a rising current that allows them to gain altitude.

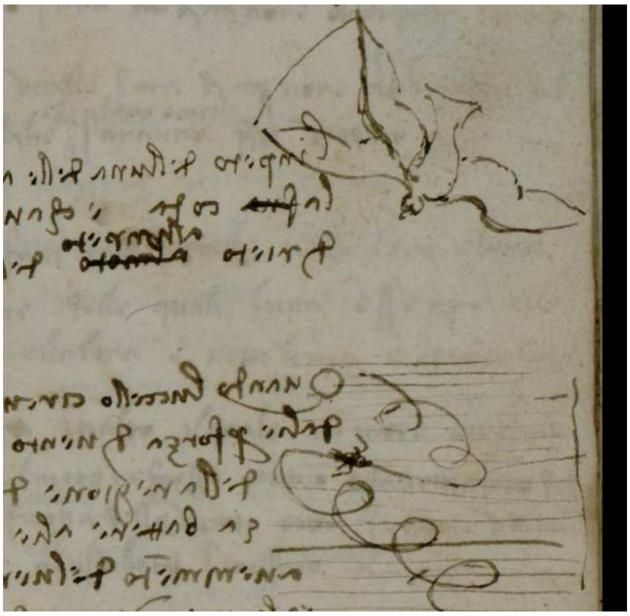

Fig. 5. Bird´s climb circular route

Observing the flapping of bird's wings, he recognized in this process two phenomena of mechanics he had already discovered. The first was that, unlike the water, "air has the capacity to compress and to expand almost infinitely," he notes, adding that only large birds with considerable wingspan can fly in the fine air of high altitudes. The second was the principle, now known as Newton's third law, according to which, for every physical force, there is an equal and opposite reaction force. In the Codex *Atlanticus*, folio 158v, Leonardo mentioned the two phenomena several times and, from very early on, used their combined effect in an attempt to explain aerodynamic lift. [9]

The aerodynamic lift also would be explained by the action or compression of the air under the wings and bird´s body, and their reaction, that is, the application of Newton's third law that was known only about two hundred years later, in the seventeenth century.

Still according to Capra [9], in the Codex *Atlanticus*, at the same time, Leonardo concluded that: “For these reasons, which we establish and demonstrate, a man with his great articulated wings, exerting pressure against the resistance of the air and surpassing it, will be able to rise.” Thus Leonardo's belief in the possibility of human flight had existed since his early research. All his life, he cultivated this certainty. His firm conviction that, in the future, human beings would be able to fly like birds was not based on hope, but on solid scientific principles.

Some of Da Vinci’s ideas showed a machine that would carry a man while efficiently harnessing his power. The drawings called for a pilot either prone or standing and operating the flapping wings by alternately pushing or pulling on several levers.

Leonardo made interesting observations about the bird´s gliding and it´s wings function, as Santos Dumont did in his first aircraft projects already in the early twentieth century. Da Vinci points out the pilot's position and control to achieve stability by shifting body weight, just as Santos Dumont imagined at the beginning of aviation.

As Zanon [1] said, Leonardo drew the contours of the flying machine´s pilot, already showing some features useful for device´s construction (Fig.6).

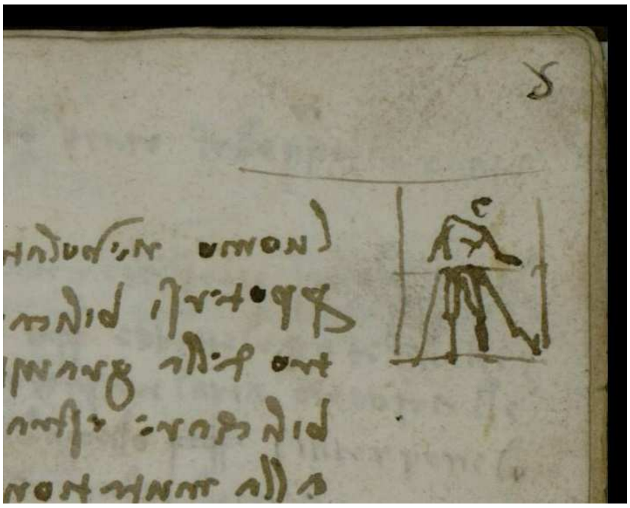

Fig. 6. The pilot in the control structure

“For example, the machine’s structure must guarantee the pilot ample freedom to move his torso so he can counterbalance the wind and the movements of the machine. There aren’t many parts to it form a constructive point of view However, we can easily infer that the pilot would assume a vertical position, as opposed to a reclining one like in other flying machines created by Leonardo. A kind of cage that is supposed to constitute the cockpit is clearly visible in the drawing, as is an upper platform, which could either foreshadow the shape of the wings or, perhaps more accurately, a platform for the many tie-rods and pulleys useful for piloting” [1] (Fig.7).

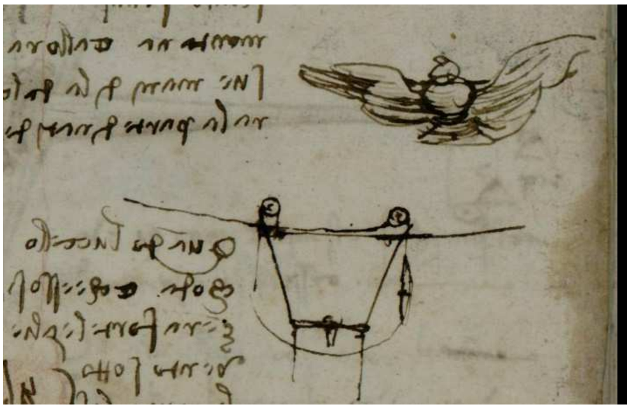

Fig. 7. Control structure

Leonardo also designed a glider with movable wings, where the pilot's position was designed to allow him to balance himself by properly moving the lower part of his body with his hands and arms being used to maintain balance and change course. Like as in modern delta wings. The wings, similar to those of bats and large birds, were rigid in their central section and flexible at the tips. Leonardo had developed this solution after having studied the structure of the bird´s wings and observing that the inside of its wings moved more slowly than the outside and that, therefore, the function of this part was to support and not too bent according to Capra's simplified explanation: “During the descent, the wings not only strike to compress the air as they fold back and inward, the ends turning towards the pilot's feet. This movement that mimics the wings of the birds, is made by means of a complex system of connections, pulleys, and springs, a masterpiece of mechanical engineering. See Fig. 8

Fig.8 Bird´s wing fold back and inward, the ends turning towards the pilot's feet.

These designs served as the basis for several fighter models built by modern engineers” [9].

In the Fig.9 the drawings of folios 16v and 17r are to be joined to form one single structure and the whole one wing mechanism.

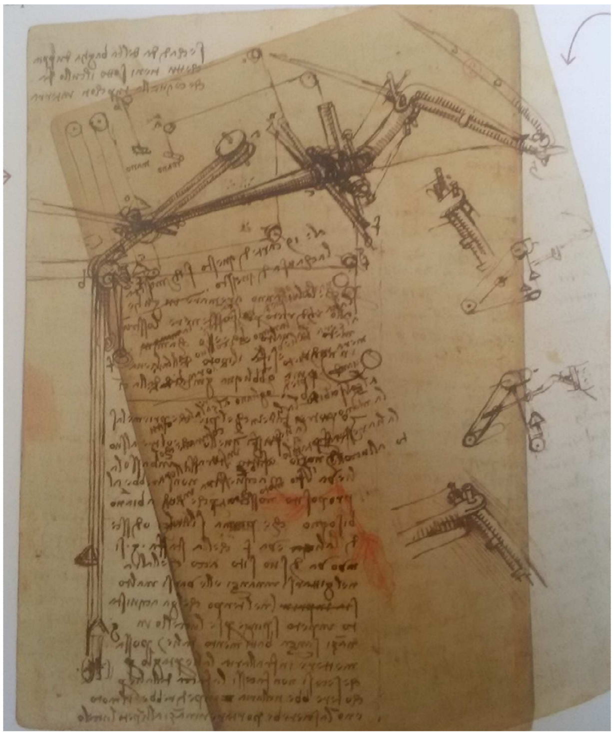

Fig.9 Folios 17r and 16v

The fig.9 shows a model designed by Leonardo, made with materials available in the Renaissance. The precariousness of these materials-wooden supports, leather strip joints and thick fabric covers-explains why Leonardo could not create a viable model of his flying machines, even though they were based on solid aerodynamic principles. The combined weight of the machine and the pilot was simply too large for muscle strength to lift him off the ground.

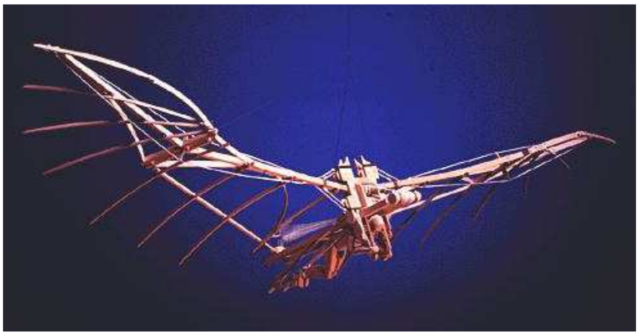

Fig.10 Built model in history and Science Florença Museum

In the Codex, Da Vinci also discusses the concept of stability and control, fundamental to the relationship between the center of gravity and the center of pressure of a wing's support [5]. He explains the behavior of bird wings as they increase the angle to the wind, the so-called angle of attack in the current aerodynamics. Fig.11

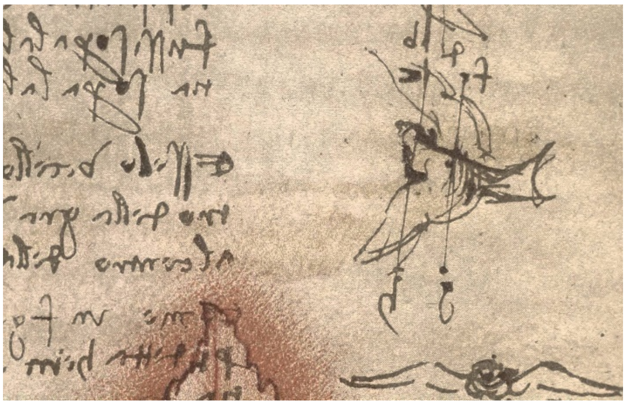

Fig. 11. CP, CG, and angle of attack

He also made anatomical studies of bird wings, learning how they were able to use their wings as brakes. Eventually, his investigations led to a decision to substitute sail-flight projects for flapping-wing machines.

Leonardo was always concerned with drawing and explaining in detail the functioning of his flying machine designs. With much emphasis on the unions, connections, and joints that was based on the human body. Once again with interdisciplinary thinking applied to the movements, which he learned when he had the permission to dissect corpses at the Hospital of

Santa Maria Nuova in Florence and later at the hospital in Milan and Rome. Between 1510 and 1511, the physician Marcantonio Della Torre [3] collaborated in his studies, and together they elaborated a theoretical work on the anatomy, in which Leonardo made more than 200 drawings.

At about sixty years old, Leonardo converged his empirical thoughts to more scientific theories in a small notebook, called the manuscript E. He declares that his science of the winds is based on aerodynamics or fluid dynamics. Leonardo reviews three of his most important discoveries in aerodynamics. The first is that air, unlike water, is compressible. "The air can be compressed and thinned almost infinitely," he notes, adding that only large birds with considerable wingspan can fly in the fine air of high altitudes [1]. Leonardo's second major discovery in aerodynamics is the wind tunnel principle, that is, the relativity of motion between a solid object and the surrounding air. Its formulation in Manuscript E is practically identical to the one it had given ten years before in the Codex *Atlanticus*. The third finding is the distribution of pressure enclosed by the wings of the birds, that is, the pressure is higher on the lower surface and lowers on the upper surface.

Interesting Coincidences

Leonardo was the first to recognize, and to formulate clearly, the principle of motion relativity, according to which a body moving through the air is the same of a body immersed in a stream of air. "Moving the object against the still air," he wrote around 1505, "is the same as moving the air against the motionless object." Today, this is known as the principle of the wind tunnel, the most important experimental aerodynamic tool [1].

In the year 1505 when nobody could imagine flying, Leonardo da Vinci had designed a flying machine with almost the same dimensions as the hang glider. On codex folio 12v. Leonardo indicates the wingspan about 30 *braccia* or 18-meters, the same of a Jonker JS-1[1], a competition glider, 18 meter class. In the same folio, he also defines the center of gravity position, as below wing level near the leading edge. At these dimensions, the machine had a significant wing surface of about 35 square meters. Due to a large amount of wood required, about 250 kg plus 70 Kg, the pilot`s weight, it gets a total of 320 kilograms. The wing loading would, therefore, be about 9 kilograms per square meter, the same as an Icaro 2000[2] a famous hang glider.

Final considerations

The current theories on interdisciplinarity aim at integrating disciplines into new approaches, new concepts, premises, and paradigms. Leonardo did not live in the world of his time, important for him were the observation of nature, mind thinking, movements, interconnectedness of the knowledge of the different disciplines.

Leonardo was an interdisciplinary scientist, one who had the knowledge with a wide range of diversified disciplines to be able to produce, on its own, a synthetic explanatory model of a complex reality. A man who knows how to play all instruments of the production of knowledge.

It can be emphasized that, in today's more important world, interdisciplinarity has always been present in the learning, knowledge, and imagination of humanity and will always be a process of collaboration and dialogue between disciplines, obviously within the limits and reality of each one and it is indispensable for a world permeated by problems of great complexity that challenge contemporary science.

By seeing and looking at everything that was around him, under various angles that went unnoticed by all, it seemed that Leonardo was transported to the future and felt possibilities that were, for him, to be probabilities. He excelled in all the excellences of which of man generally lacks. His imagination allied with unusual

[1] It´s a glider JS-1 Revelation which won the 18 meter class South African National Championship in 2008

[2] Hang glider 2016,2017 World Champion

intelligence led him to other worlds that people could not even imagine existed.

In conclusion, superior intelligence, like Leonardo Da Vinci, seemed to have fused science and art to create works that have become part of humanity's story. Leonardo then blurred the line between fantasy and reality when he went on to create real flying machines that were engineering marvels! Leonardo Da Vinci had no limits.

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