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Flying Sphere image © Museo Ideale L. Da Vinci

Leonardo, the wind and the flying sphere

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ABSTRACT

The Logo of the 5th European and African Conference on Wind Engineering has been obtained by re-elaborating a drawing by Leonardo da Vinci, representing a flying sphere carrying a male body in its center. In the papers, a short view of some of Leonardo's idea related to wind and flight are illustrated. Finally, the “flying sphere” is described and, after a research work carried out by CRIACIV, the results of some wind tunnel tests are reported

1. LEONARDO AND THE WIND

Leonardo da Vinci (Vinci, Italy, 1452 - Cloux, Amboise, France, 1519) has been celebrated, as well as an exceptional artist, as the inventor of machines and mechanical devices that will have become the common heritage of technical culture only several centuries after his death.

Leonardo was a great observer of the nature from which he found inspiration for his paintings, but he also tried to extrapolate the laws that govern its mechanisms. Relying primarily on the direct experience he deals with many physical phenomena, writing treaties on botany, anatomy, geology

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and hydraulics. Among the other branches, he devoted a lot of investigations in the field of the flying machines and of the fluid dynamics.

1.1 Leonardo and the flying machines

The dream of flight is lost in the mists of time. Starting from the famous myth of Dedalus and Icarus, the stories and the chronicles record several attempts - usually unsuccessful - made by fearless experimenters: Suetonius recalls for example the case that the claimant Roman in 60 A.D. died making a launch during a party organized by Nero to celebrate the eternity of the Empire. In turn fifteenth report chronicles the case of the more fortunate Giovanni Battista Danti who, in an attempt to fly across the Piazza Grande of Perugia, ends up on the roof of a church nearby and managed to get by.

All of these primordial airmen have in common the same idea: to simulate the flight of a bird, and therefore the use of the wings attached to the shoulders or arms. Leonardo also based his study on observation of birds: unlike all his predecessors, however, he develops a genuine theory of flight, from which develops the design of its machines. The studies will extend to the laws of physics, air, wind and their behavior.

The parachute

The first approach of Leonardo with the design of flying machines came in 1485 with the realization of a prototype of parachute: it was a rigid structure in the shape of a square-based pyramid covered with linen that should not present openings. Leonardo says that thanks to the parachute, the man *"potrà gettarsi da ogni grande altezza senza farsi male"* ("can jump from any great height without injury").

This one, as well as other Leonardo's ideas, has hit the fantasy of many people along the century so that several attempts have been made to really use the shape of the parachute reported by Leonardo. Among others, a Swiss adventurer proved in 2008 that Leonardo's pyramidal-design parachute could carry the weight of a man all the way to the ground (even if his chute did not incorporate Leonardo's original design, which called for four equilateral fabric triangles anchored by a wood-frame base, but it was made of modern fabric and mosquito netting instead).

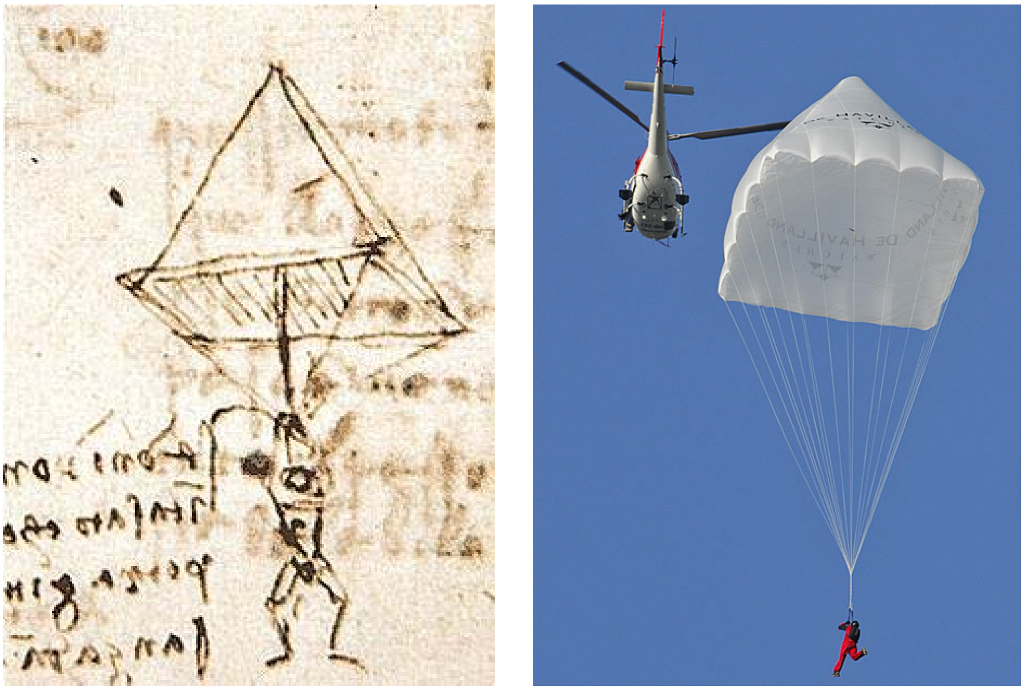


Figure 1: the parachute (left: a Leonardo's drawing from Atlantic Code, ex 381v-a (1058v), c.1485; right: one of the parachute built according to Leonardo's drawings)

Screw air

Contemporary to parachutes there is another idea based on the same principle of resistance: the so-called screw air. Designed between 1483 and 1486 during the first stay in Milan, the screw air belongs to the first series of machines designed by Leonardo for the flight mechanic. Its original destination, however, was that of studying the efficiency of the propeller (o helix), not being a real machine for the flight. Made of cane, linen and iron wire, the facility should be driven by four men who were supposed to stand with their feet on the central platform and to rotate the shaft with their hand's strength. Thus conceived, however, the screw air could hardly rise from the earth. The fact remains that with appropriate driving force behind the instrument it could be able to raise. The intuitions of Leonardo was in fact taken by Enrico Forlanini in his steam helicopter and then optimized by modern helicopter, which can be recognized as the direct descendants of the screw air.

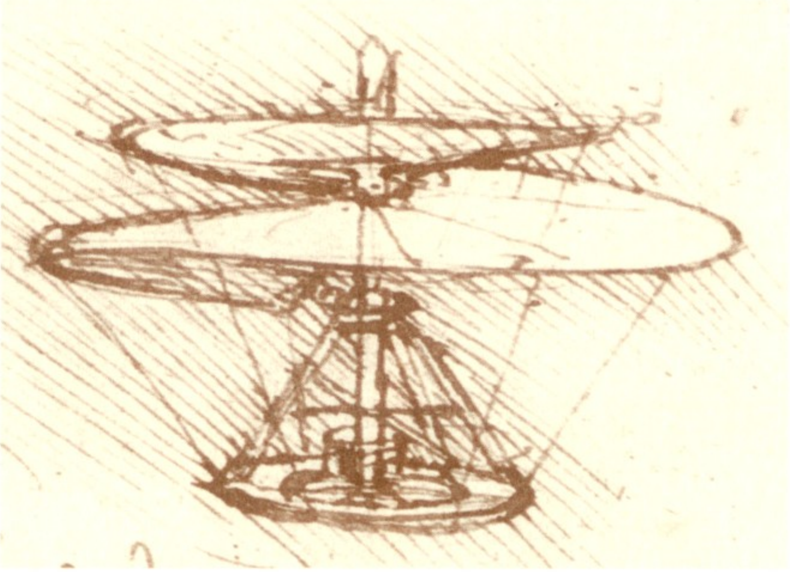


Figure 2: screw air (one of Leonardo's drawings, Istitute de France, Paris, B 83v, c.1487)

During its first period of stay in Milan Leonardo devoted himself to the study of various flight machines which, through complex mechanisms, should rise only exploiting human muscle power.

Leonardo develops different types of wings, like the one in the shape of a bat and uses different materials, the wood of spruce, the moleskin covered with feathers and taffeta starched stretched over a loose network.

Vertical "ornitottero"

In this flying machine wings are arranged in pairs. The pilot is in a vertical position at the center of a complex system for the transmission of the movement. This machine not only uses the force of arms and legs but also that given by the head. The stairs are retractable and equipped with dampers.

Bicycle "ornitottero"

The bicycle ornitottero is one of the variants of "ornitottero prone" (with the pilot in a horizontal position). In this version the rider is positioned on the middle board, while the propulsion system is driven by strong cycling. This flying machine requires alternative movements of hands and feet; these movements move the wings through a transmission system of ropes, pulleys, couplings and cranks. Note the tool positioned on the head of the pilot, an inclinometer, useful for the balance during the flight.

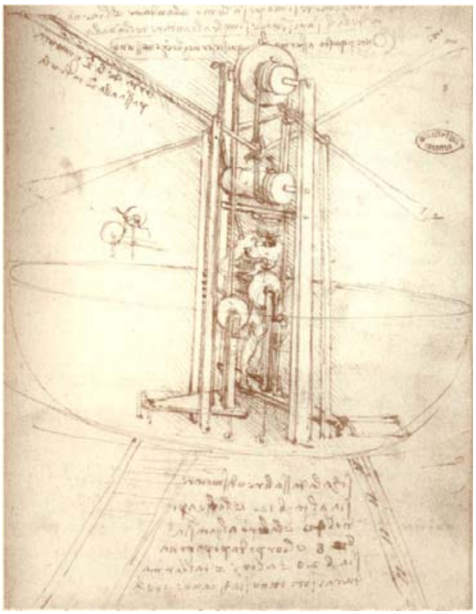


Figure 3: vertical “ornitottero” (one of Leonardo’s drawings, Istitute de France, Paris, B 80r, c.1487)

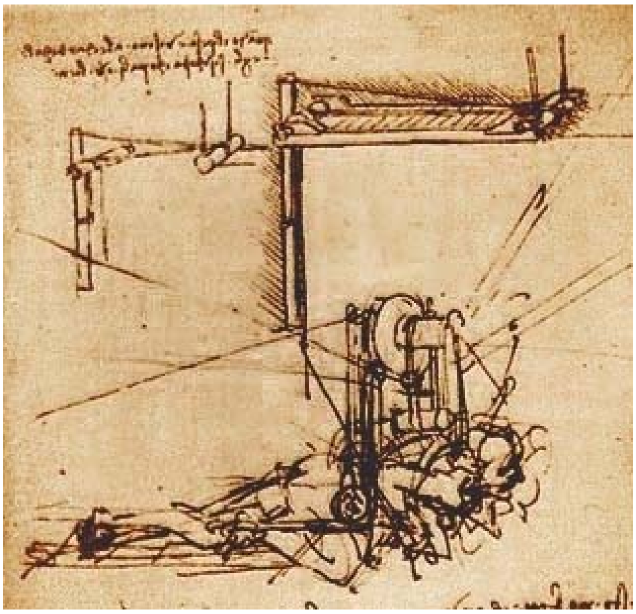


Figure 4: bycicle “ornitottero” (one of Leonardo’s drawings, Atlantic Code f327 v-a [897 r] 1485)

Aliant (“ornitottero” wing)

The flying machines that Leonardo experimented, however, did not work as expected.

The driving force was the main obstacle which Leonardo encountered: no man had strength enough to move his machines, most of which having beating wings.

Trough detailed observations on the flight of the birds Leonardo noticed a great difference: the birds of small size sustain their flight trough the quick beating of the wings, while the medium-large birds, especially the raptors, sailing and taking advantage of the current. This is a flight that does not require a large energy.

Since then he abandoned the search on beating wings and addressed his studies in “volo librato”, possible with machines provided of fixed wings.

The large wings that Leonardo imagined for the aliant are analogous to those of rapacious and derive from extensive observations on the flight of birds.

The wing is designed to be partially fixed and has a structure divided into two parts: the inner part, closer to the pilot, is stable and will support it in flight, the outside is mobile and can be controlled for correcting the direction. The pilot, positioned at the center, has not (as in other flying machines) the task of operating the propulsion, but needs only to balance the entire structure with its own weight on its own movements. He also acts, through handles, on court and pulleys to tilt the movable ends of the wings.

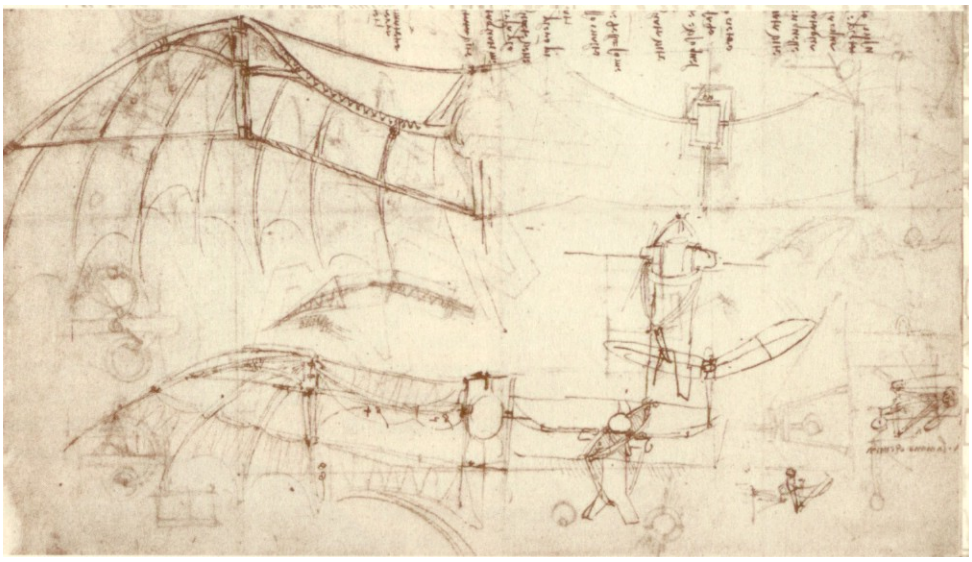


Figure 5: Aliant (“ornitottero” wing): one of Leonardo’s drawings, Atlantic Code ex 309v-a (846v), c.1493

1.2 Leonardo and the fluid-dynamics

Leonardo da Vinci starting to examine the natural world of fluids and flow in detail. He observed natural phenomena in the visible world, recognizing their form and structure, and describing them pictorially exactly as they were. He planned and supervised canal and harbour works over a large part of middle Italy. His contributions to fluid mechanics are presented in a nine part treatise (*Del moto e misura dell'acqua*, Cardinale 1828) that covers water surfaces, movement of water, water waves, eddies, falling water, free jets, interference of waves, and many other newly observed phenomena.

Leonardo also pioneered the flow visualization genre close to 500 years ago. Much of Leonardo's notebooks of engineering and scientific observations were translated into English in a magnificent two-volume book by MacCurdy (1938). In there, one can easily discern the Renaissance genius's prophecy of some of the flow physics to be discovered centuries after his time. Particularly relevant to the modern notion of coherent structures, the words eddies and eddying motions percolate throughout Leonardo’s treatise on liquid flows.

In following Figure 7 is reported perhaps the world first use of visualization as a scientific tool to study a turbulent flow.

Gad-el-Hak (1998) reports that around 1500, Leonardo sketched a free water jet issuing from a square hole into a pool. He wrote *“Observe the motion of the surface of the water, which resembles that of hair, which has two motions, of which one is caused by the weight of the hair, the other by the direction of the curls; thus the water has eddying motions, one part of which is due to the principal current, the other to the random and reverse motion”*. In describing the swirling water motion behind a bluff body, da Vinci provided the earliest reference to the importance of vortices in fluid motion: “*so moving water strives to maintain the course pursuant to the power which occasions it and, if it* *finds an obstacle in its path, completes the span of the course it has commenced by a circular and revolving movement*". Leonardo accurately sketched the pair of quasi-stationary, counter-rotating vortices in the midst of the random wake. Finally, da Vinci's words (*". . . the small eddies are almost numberless, and large things are rotated only by large eddies and not by small ones, and small things are turned by both small eddies and large"*) presage Richardson's cascade, coherent structures and large-eddy simulations, at least.

Figure 6: one of the Leonardo’s drawings in the field of fluid mechanics

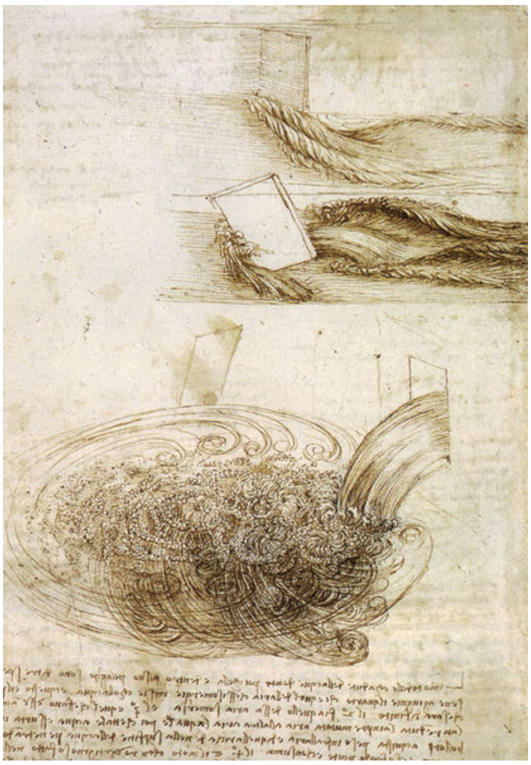
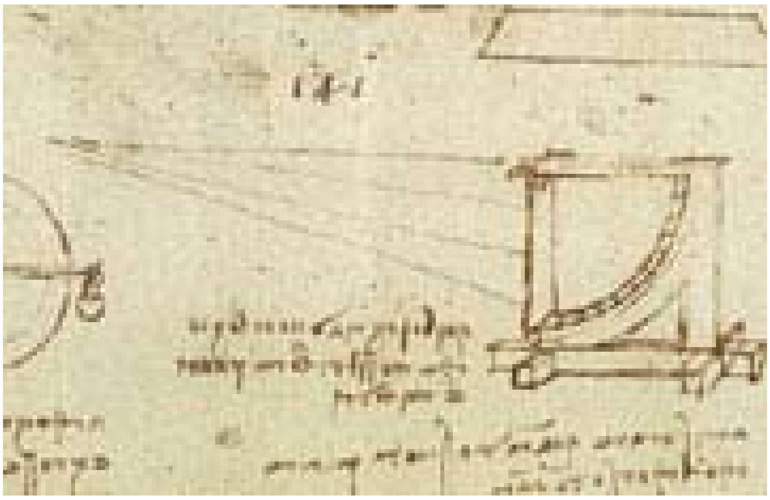


Figure 7: two studies of fluid mechanics by Leonardo da Vinci

Anemometers

Leonardo invented at least two different anemometers. The anemometer reported on left-hand side of Figure 8, drown by Leonardo, is called “strip” or “brush”. It is a simple graduated wood with a blade that moves depending on the strength of the wind. The anemometer is surmounted by a weathervane (“*banderuola*”), to indicate the direction of the wind. The instrument was used for the study of weather conditions, to ensure the safety of the flight.

The other one (right-hand side of Figure 8) is an instrument which gauges the speed of the water and wind through two conical holes and rotor blades.



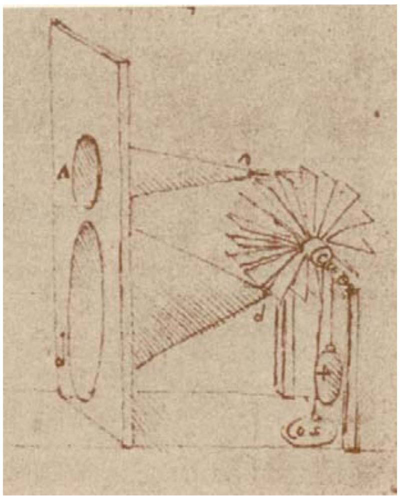


Figure 8: two anemometers invented by Leonardo (left: from Atlantic Code, ex 249v a-b (675r), c.1487; right: from Arundel Code, British Library, London, 241r, c.1490)

2. THE “FLYING SPHERE”, LOGO OF 5TH EACWE

Amongst several other worldwide known sketches and drawings, this one remained quite unknown since it has been discovered only in 1966, as a part of a Code found in Madrid’s Library, but (as usual for the Genius of Vinci) it offers several very interesting aspects.

First of all, among all the “flying machines” conceived by Leonardo, the symbolic content of this one is very impressive: the human being is therefore *assigned* to the center of the giant flying object and is always dominating the machine and its elements. The human being is acting like the magnetic needle of a compass, and his movements cause the object to rotate.

The description, in ancient Italian delivered by Leonardo, is quite impressive, and it can hardly be translated into English:

> *“Sia fatta una simile ventola, come qui è figurato, e sia composta di zendalo, corde, canne e aste, di diamitro 20 bracci o più. Nel mezzo della quale sia collocata una balla traforata, fatta di cierchi verdi, che sieno d’olmo. E sia detta balla con tali cierchi aconcia a uso di bussola di calamita, e nel mezzo d’essa balla stia un omo. E sia tale strumento collocato sopra uno monte, al vento, e tale strumento s’acompanierà col dorso de’ venti, e ll’omo sempre starà in piedi”*

More or less, in English this paragraph would sound like: “*One builds such a “fan”, like the one reported in the figure, made out of clothes, rods, reeds and trusses, with a diameter of 20 arms or more. One places in the centre an open-work light bale, made by green rims, circles of elm-wood. And that bale with such rims will be mounted like a lodestone in a compass, and in the middle of the bale a man will stand. Such a tool will be placed at the top of a hill, toward the wind, and such tool will move riding the ridge of the winds, while the man will always stand*”.

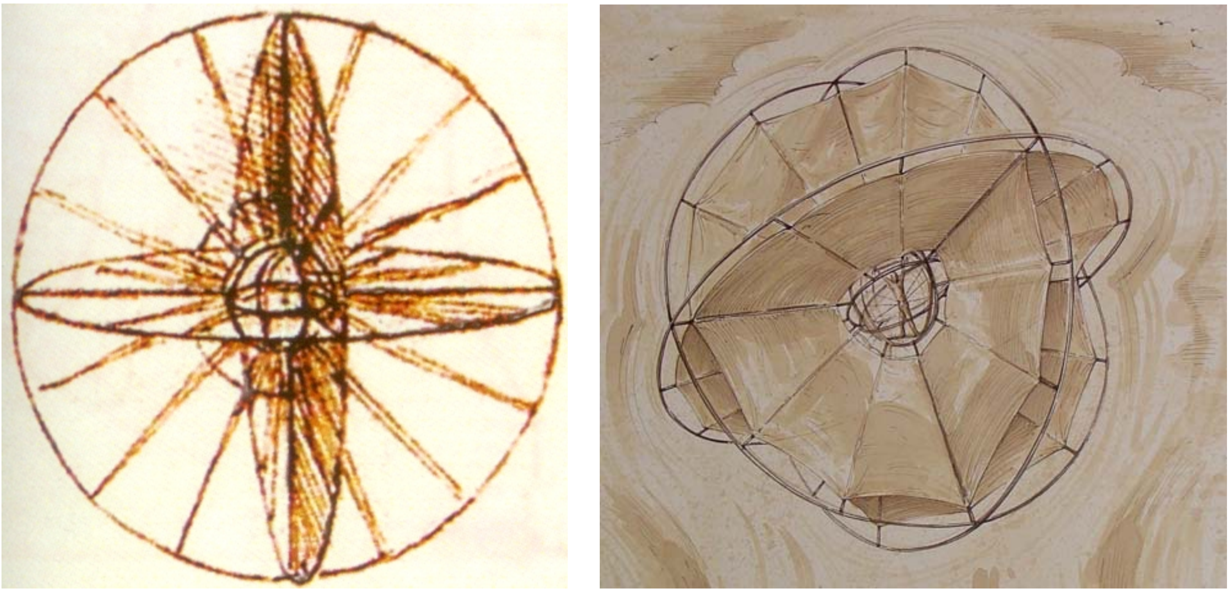


Figure 9: the “flying sphere” (left: the original drawing made by Leonardo, Madrid Code; right: reconstruction of the Leonardo’s idea)

As it can be immediately realised, Leonardo did not only imagine the “shape” of his invention, but he also took care of the materials to be used. This is only one of many studies in which Leonardo, after having developed a project, kept on searching for forms and materials which were more and more suitable to the innovative functions of the new machine.

This is the reason why he introduced and experimented new materials; he forecasted the use of “plastic” materials, by creating his “*mistioni*” (mixtures) which could have been used to make jewels and tools, and those “unbreakable objects” that “*gittati a terra non si romperanno*” (even if thrown down would never break).

Leonardo mentioned the steel (“*acciaro*”), he studied coals and resins; he elaborated formulas for chemical compounds, by distilling acids and other substances equivalent to nail polish remover.

Moreover, a great effort was devoted by Leonardo to the investigation of modular structures, joints and materials for every light and resistant sail.

3. WIND TUNNEL TESTS ON THE “FLYING SPHERE”

The Museo Ideale Leonardo Da Vinci in collaboration with Studio M in Florence has identified in the idea of Leonardo's Flying Sphere one of the most ambitious projects with reference to the dream of human flight.

Under this, recently, they developed the idea of reproducing, at full scale, Leonardo’s dream of the “flying sphere”, built for the first time in compliance with the insights and methods of Leonardo.

For this purpose the Studio M created projects and realized scaled models. It also carried out a specific research on materials for the construction of the prototype in 1:1 scale. The machine should be constituted by carbon-fibre tubes, with teflon of rubber joints, while the sails will be made out of kevlar.

At the centre a “cardanic” joint (named after Girolamo Cardano, born in 1501 and son of one of Leonardo’s friend, Fazio) will allow the man inside the sphere to freely rotate in the space while maintaining his erected position during the flight.

This one will be the first time in which the “Flying Sphere” will be realized at the same scale, with different materials but in the full respect of Leonardo's intuition and method.

3.1 Wind tunnel tests and results

To enable the design of the full-scale sphere, an experimental campaign of wind tunnel tests was commissioned to CRIACIV, and a 1:25 model was manufactured and placed in the wind tunnel, allowing the same degrees of freedom of the real structure (Figures 11 and 12).

Figure 10: a model of the “flying sphere”

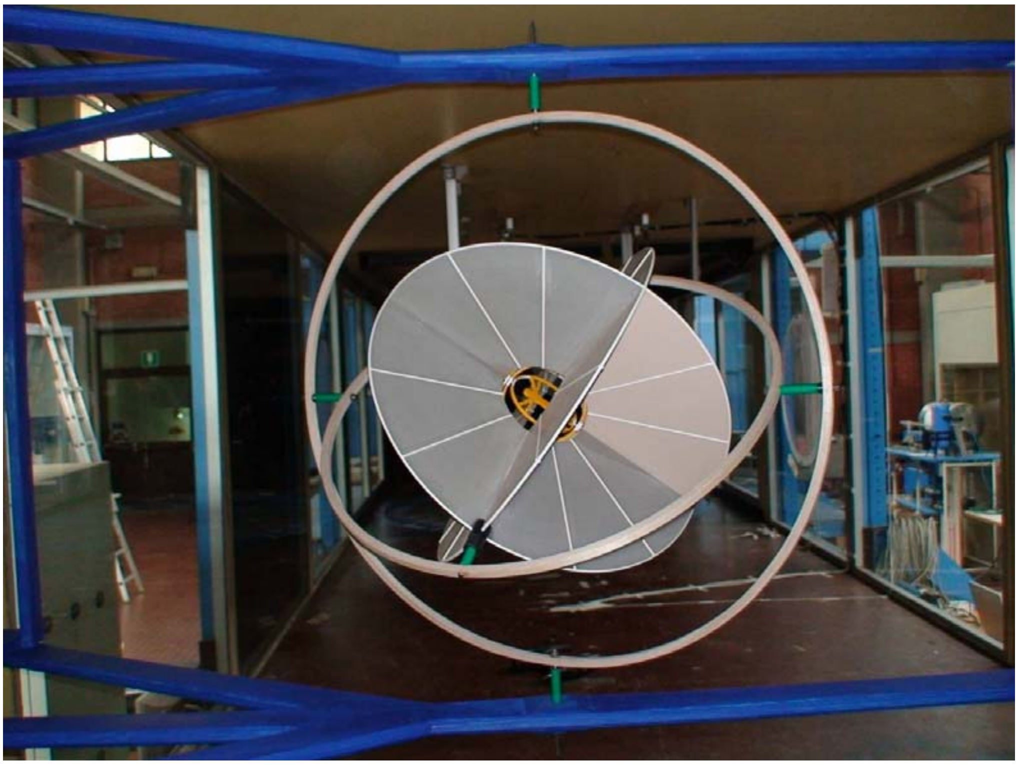


Figure 11: a view of the model in the CRIACIV wind tunnel

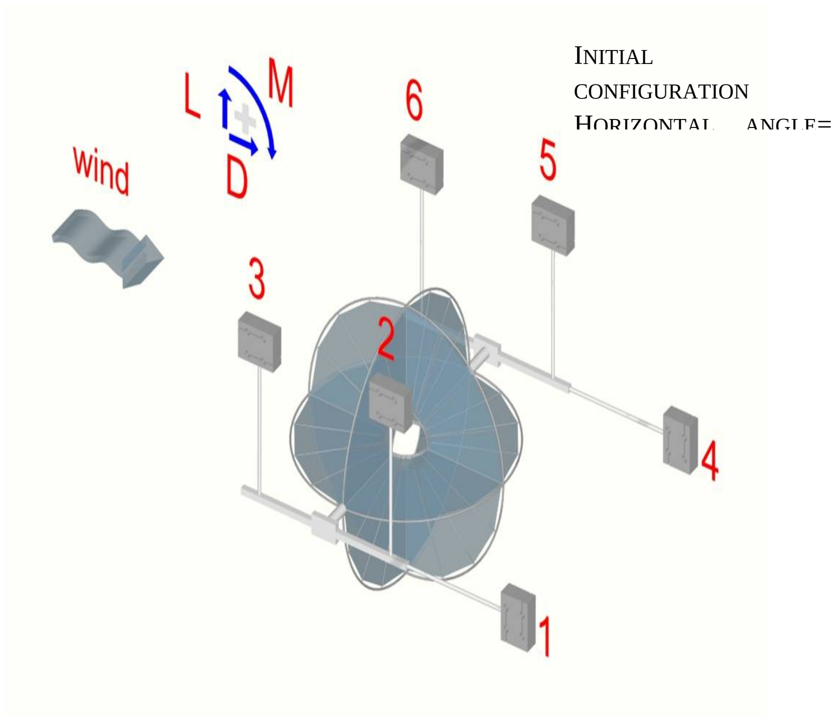


Figure 12: experimental setup for the wind tunnel force measurements (6 force measurement points) and sign convention

Several tests have been performed, in order to assess the (global) force coefficient (and hence the power necessary to make the sphere fly) and to check the “stability” of the reached positions. In fact, one has intuitively expected some wind-incoming directions which will induce a pure rotation the sphere around one of its symmetry axes.

Some of the obtained results are sketched in Figure 13. Due to confidentiality obligations, force and moment coefficients are reported in a comparative form, i.e. the real values have been normalized with respect to the maximum absolute values.

Results refer to two different configuration: in the first, wind is blowing against the diameter of one of the two main rims, and the angle of incidence has been varying along the vertical axis (horizontal rotations of the sphere); in the second test, measurement have been performed in the same way, starting from the angle 0° referred to as the other main axis (that is 45° apart and above the previous position).

3.2 Stable and unstable conditions

An unstable condition happens when one of the three rings is placed perpendicular with respect to the incoming wind direction. In this situation (in smooth flow conditions) resulting torque moment would result as null; any small perturbation (either in the flow or in the position of the sphere) would induce the sphere to move. This initial perturbation could both start a continuous rotation of the sphere or could make the sphere move toward a stable condition, which is represented by one of the configuration similar to those reported on left-hand side of Figure 14.

During tests, unstable conditions have never been reached, because of all the small imperfection related to a wind tunnel test (the model is not absolutely symmetrical and some turbulence is always present in the incoming wind).

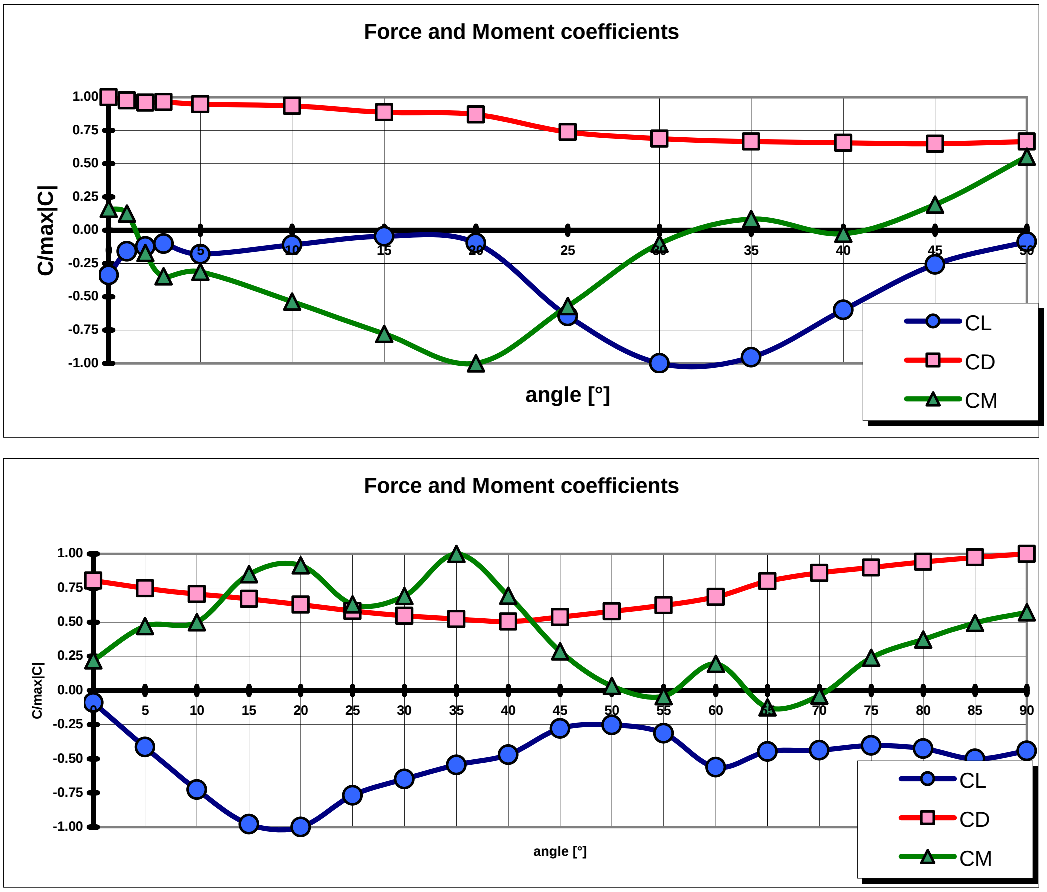


Figure 13: obtained results for two different tested configurations: angle of incidence = 0° (above), angle of incidence = 45° (below); coefficients are plotted as ratios with respect to their maximum absolute values

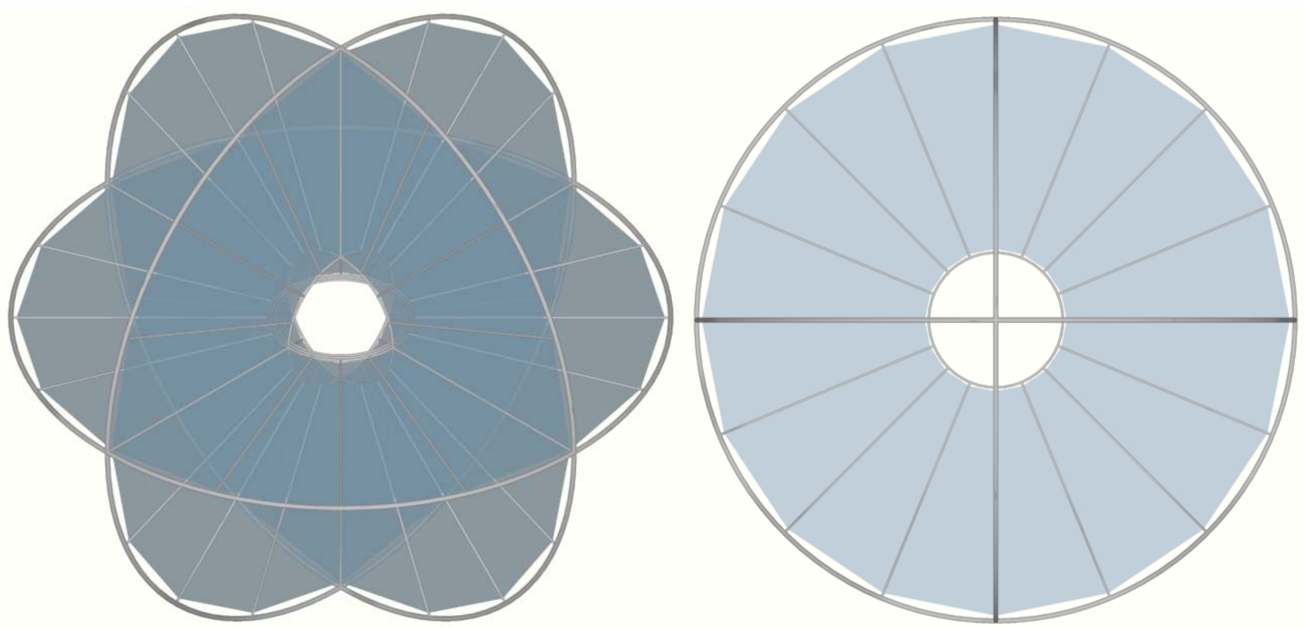


Figure 14: stable and unstable configurations (left: minimum energy configuration – stable; right: maximum energy configuration – unstable; the wind is blowing from the reader to the sheet)

4. CONCLUDING REMARKS

Obtained results still do not ensure that the “Leonardo's sphere” will be able to actually fly and being able to be somehow controlled; nevertheless, all Co-Authors found this insight into the studies about “wind and flight” of the Renaissance Genius as extremely attracting and exciting. The extreme curiosity, the degree of innovation and the tireless experimentation skills which Leonardo shown also in this disciplines made us and our modern attitude as researchers quite jealous and envious: we are deeply convinced that after six centuries his achievements may still represent a great lesson for many generations of researchers, even yet to come ...

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