Kites: the rise and fall of a scientific object

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ABSTRACT: Between 1753 and 1914, kites were used as scientific objects in different branches of physics. First, as experimental instruments in electrical experiments. Then, still in the 1750s, we find theoretical models of the flight of kites. In the late 19th century, sophisticated technological kites were also used for aerological measurement. Finally, at the turn of the past century, kites served early aeronautical researchers as scale models of wings. In all cases, there was a rise and a fall: kites were reasonably successful in all these roles, but they could not produce interesting enough results to stand the competition of more efficient alternatives.

KEY WORDS: kite, electrical kite, aerology, glider

1. Introduction: Kites as unsuccesful scientific objects

According to the *Dictionarium Anglo-Britannicum*, in Old English the word *kite* referred to “a bird of prey” (of the genus *Milvus)*. Only in the 1660s, we find it naming a toy that hovered in the air like kites did. Probably, most of us are today more familiar with the toy than with the bird. At least, in the current version of the *Oxford English Dictionary*, we find *kite* initially defined as “a toy consisting of a light frame with thin material stretched over it, flown in the wind at the end of a long string”. But, in between 1753 and 1914, the word *kite* discontinuously also referred to various kinds of scientific objects, all now gone. In this paper, we will briefly present these scientific kites, tracing the causes of their rise and fall.

Before science, kites were already loaded with multiple meanings. Its origins are apparently in ancient China, where it was used for religious and ritual purposes.[1] In Japan, it featured in a competitive game played between different social groups.[2] In Oceania, kites became a fishing tool[3]. Between the 15th and 17th centuries, already in Europe, we find kites in books on natural magic and alchemy as well as in several treatises on war machines.[4] But it was as toys that kites achieved their greatest success.[5]

And yet, during 160 years, kites also played various roles in science, nowadays mostly forgotten. As we are going to see, kites briefly featured in the History of various branches of physics in at least four categories. In 1753, they became part of Benjamin Franklin's experimental setup to prove the electrical nature of lightning, attaining briefly the consideration of *scientific instruments*. Soon afterwards Johan Albert Euler developed a *theoretical model* of flying kites rational mechanics. In the late 19th century, several engineers developed innovative designs of kites in order to use them in the elevation of meteorographs to the higher layers of the atmosphere, making them *auxiliary tools* in meteorological measurement. By the 1890s, with the origins of aviation, kites became *scale models* of gliders' wings, successfully contributing to the tests that led the Wright Brothers to make their airplane prototype fly.

The interesting historical fact is that kites never became successful scientific objects in any of these capacities. Defining scientific success might be controversial, but

[1] Needham, Joseph, *Science and Civilisation in China vol. 4, Pt. 2* (Cambridge, Cambridge University Press, 1965), pp. 568-602. We are grateful to Michael R. Lynn, Susan Sterrett and two reviewers for their comments. Teira's research has been funded by the Spanish research grant FFI2011-2883.
[2] Hart, Clive, *Kites an Historical Survey* (New York, Paul P. Appel Publisher, 1982), pp. 33-49.
[3] Barton, Garry & Dietrich, Stefan, *This Ingenious and Singular Apparatus. Fishing Kites of the Indo-Pacific* (Heidelberg: Völkerkundemuseum vPST, 2009).
[4] For example see: Milemete, Walter, *De Nobilitatibus Sapientii et Prudentiis Regum* (London: Ed. M. R. James, 1326/1913), pp. 154-155; Kyeser, Konrad, *Bellifortis* (Göttingen: GNiedersächsische Staats und Universitätsbibliothek, 1405), Codex 63, ff. 104v., 105r; Porta, G. B. della, *Magia Naturalis,* (Naples, 1558), pp. 69-70 and Bate, John, *The Mysteryes of Nature and Art* (London: Thomas Harper for Ralph Mab, 1634), pp. 80-82.
[5] Hart, *Kites* (cit. note 2), p. 86.

for the sake of the argument, we may simply say that kites never became an established item in a Kuhnian paradigm, a standard illustration of the application of a given theory, be it conceptual, instrumental, etc. Yet, kites did not become successful scientific objects for the errors they generated, but rather for lack of *epistemic productivity*, in Daston's sense:[6] the scientific results that kites delivered were modest and in all cases it was soon discovered that they could be attained more efficiently by alternative means. In our view, it is interesting to explore kites as an unsuccessful *scientific object* not in the usual sense of one that was proven erroneous or incorrect, but rather one that could not stand the test of scientific competition. However, even after their scientific productivity was exhausted, their success in grasping the attention of the public kept them within the boundaries of science for a few more decades.

We will present our case in chronological order. In section 2 we will introduce electrical kites, the experimental setup with which Franklin and Romas established the electrical nature of lightning, and the theoretical model developed by Euler in order to improve the flight of electrical kites. In both cases, the scientific career of kites unfolds in two stages, going from scientific treatises to recreational science texts, where they remained for the longer part of their career till the end of the 19th century. In section 3, we will study how new models of kites were designed according to scientific principles in order to serve the need of the emerging discipline of aerology by the 1850s. In section 4, we will study the role that kites played as *scale models* of wings at the beginning of aeronautical research. We will close with a brief reflection on how the study of this unsuccesful scientific object might increase our trust in scientific research.

[6] Daston, Lorraine (Ed.), *Biographies of Scientific Objects* (Chicago: University Chicago Press, 2000).

2. Electrical Kites

For most readers of this paper, Franklin's lightning experiment will be the only known instance of a scientific use of kites. This is perhaps evidence for our main claim in this section: the public fascination with Franklin's experimental setup fueled the scientific career of kites. Let us briefly recall it.

In a letter dated on October 19th, 1752 and published the following year in the *Philosophical Transactions* of the Royal Society,[7] Franklin declares that he had flown a kite in a storm with a pointed wire on top. At the end of the string, he tied a silk ribbon and key. The wire drew the "electric fire" from the thunder-clouds and conducted it through the wet string to the key, where the experimenter noticed it when approaching "a knuckle". With the electrified key, Franklin was able to perform "all the other electric experiments" (for instance, charging a Leiden jar, a proto-capacitor), showing the "sameness of the electric matter with that of lightning". This experimental setup was soon referred to as an *electrical kite*.

Franklin's kite experiment is a variation on his previous *sentry box* set up, in which the iron rod had been placed on top a high tower. This latter experiment had been successfully conducted by Thomas-François Dalibard in the French city of Marly on May 10, 1752 –and communicated to the *Académie des Sciences* three days later. The electrical nature of lighting was therefore already established. The spread of lightning rods all over Europe during the following decades[8] would just confirm it many more times. Other experimental physicists, such as Ebenezer Kinnersley and John Lining in

[7] Franklin, Benjamin, "A Letter of Benjamin Franklin, Esq; to Mr. Peter Collinson, F.R.S. Concerning an Electrical Kite," *Philosophical Transactions of the Royal Society of London*, 1753, ILVII: 565-567.
[8] Heering, Peter, Hochadel, Olivier & Rhees, David J. (ed.), *Playing with Fire. Histories of the Lightning Rod* (Philadelphia: American Philosophical Society, 2009), p. 9-10.

America[9] or Pieter van Musschenbroek[10] in Europe soon replicated Franklin's experiment obtaining the same conclusions. In other words, the electrical kite was not a particularly productive experimental setting. However, despite his many achievements, the kite experiment is still today part of Franklin's public image, as the following set of illustrations attest (see Fig. 1).

(Fig.1 here)

Franklin was apparently not the only one to think of this particular experimental setup: a certain Jacques de Romas (1713-1766) claimed to have successfully used it in Nerac (France) on May 14 1753. Although Romas' priority claim was apparently ungrounded,[11] he also contributed to popularize the use of kites in Europe, generating its own iconography as well.

Electrical kites constituted thus a sticky icon.[12] Its popularity was also probably boosted by the various public shows in which Romas replicated his experiment that same year. He even added a gory touch: instead of a key, he tied pigeons and dogs to the end of the string (Fig. 2) and their death proved the electrical nature of lightning – something van Musschenbroek had already tried.[13] Further public replications in America and Europe[14] drew on the same combination of entertainment and spectacle, so

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[9] Cohen, I. Bernard, *Benjamin Franklin's Science* (Cambridge MA: Harvard University Press, 1990), pp. 106-107.
[10] Musschenbroek, Petro van, *Introductio ad Philosophiam Naturalem. Vol I* (Lugduni Batavorum: Apud Sam. Et Joh. Luchtmans, 1762), pp. 295-296.
[11] Cohen, *Benjamin* (cit. note 9), p. 104.
[12] Interestingly, as one reviewer observes, despite the rhetoric success of the lightning rod, the material device did not spread all over Europe until the 1780s. Hence, the electrical kite icon took off even when the practical implications of the experimental setup for the everyday life had not been explored in full. See Hochadel, Oliver, "'In Nebula Nebulorum': The Dry Fog of the Summer of 1783 and the Introduction of Lightning Rods in the German Empire," in *Playing with Fire*. *Histories of the Lightning Rod*, edited by Heering, Peter, Hochadel, Olivier & Rhees, David J. (Philadelphia: American Philosophical Society, 2009), pp. 45-70.
[13] Musschenbroek, *Introductio* (cit. note 10), pp. 295-296.
[14] Mottelay, Paul Fleury, *Bibliographical History of Electricity and Magnetism* (London: Charles Griffin And Company Limited, 1922), p. 320.

characteristic of 18th century science: as Franklin himself put it,[15] amateur experimentalists excited lay curiosity with their demonstrations, even if they sometimes had to bear their unexpected consequences. In 1759 Romas organized yet another replication in Bordeaux, storing the kite in a nearby café while the storm arrived: it came too quickly and a lightning stroke the café before Romas could even start. The owner blamed it on Roma's setup and destroyed it.[16]

(Fig.2 here)

In 1753, only a year after the first flight of an electrical kite, the main scientific conclusion of the experiment was conclusively established. However, replications were quickly becoming a public show that explains why electrical kites still enjoyed several decades of attention in physics. At their scientific best, during the second half of the 18th century, these kites played two different roles: we find a theoretical model of the flight of kites in rational mechanics, on the one hand; and, on the other hand, they feature as scientific instruments in treatises on electricity. On both accounts, as we are going to see, kites lacked *productivity*: once established the electrical nature of lightning, they yielded no further interesting result. Yet, in both cases, they outlived their lack of productivity, shifting from scholarly texts to popular science outlets in the 19th century. In our view, this is evidence of how popular attention drove the scientific career of kites: once the public lost interest in them, by then end of the century, kites vanished from physics. Let us quickly review this career.

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[15] Sutton, Geoffrey V., *Science for a Polite Society. Gender, Culture, and the Demonstration of Enlightenment* (Oxford: Westview Press, 1995).

[16] Hart, *Kites* (cit. note 2), p. 100 and Berger, Gérard & Amar, Sonia Ait, "The Noteworthy Involvement of Jacques de Romas in the Experiments on the Electric Nature of Lightning," *Journal of Electrostatics*, 2009, 67, (2–3): 531–535, p. 534.

In 1758, five years after Franklin's and Romas' experiments, Johann Albert Euler (1734-1800) publishes a report on the flight of kites in the transactions of the *Académie Royale des Sciences et Belles Lettres* of Berlin. The contribution of Euler *le fils* belongs in the study of hydraulic machines undertook by rational mechanists throughout the 18th century. Leonard Euler published several *memoires* on the topic in the same outlet between 1752 and 1756, in parallel to his theoretical work on fluid mechanics. His son published three, the second of which was on *Des Cerf-volans*.[17] These works on hydraulic machines usually follow a similar template. The problem is stated in the introduction; then a geometrical model of the machine under study is presented. The laws of mechanics are applied to this machine, using a physical model of the fluid where they operate. These reports close with a collection of practical problems, discussed and solved in an algebraic fashion, often with numerical examples and rules for improving the design of the machine.

For Johan Albert Euler, Romas' experiments transformed kites into objects worth of scientific consideration:

> Since, so far, kites have only served as toys for kids, the research I undertake here will seem not worthy of Geometry [...] But if we agree that children's games should not stop the inquiries of a geometer, I hope nobody will object that I have considered [kites], after the famous Mr. Romas so succesfully used one such kite in his electrical experiments; dignifying this toy, he has introduced it into physics[18]

[17] Euler, Johann Albert, "Des Cerfs-volans," *Histoire de l´Académie Royale des Sciences et Belles Letters, année MDCCLVI*, 1758: 322-364.

[18] " Comme les Cerf-volans n´ont servi jusqu´ici que de jouët aux enfans, les recherches que j´entreprens, paraîtront peu dignes de la Géométrie [...] Mais, quand on accorderoit que des jeux d´enfant ne doivent pas arrêter les regards d'un Géomètre, personne cependant à ce que j'espère, ne me reprochera de m'être occupé de celui – ci, depuis que le célèbre Mr. de Romas s'est servi avec tant de succès d'un semblable

Euler would address a practical problem raised by the experiment: how to make kites reach the highest possible altitude in order to reach storm clouds. He proceeds to transform kites into a geometrical object whose physical behavior is explained by the action of a set of forces: the wind, the weight and the tension of the string. From a mechanical standpoint, kites became akin to the sails of windmills studied by Leonard Euler[19]. Johan Albert constructs then different models of the impact of the wind on the kite, and then puts forward several calculations of the height a kite may reach depending on its size and wind speed.

However, kites did not have any theoretical posterity in physics after Johan Albert Euler: with the sole (but not significant exception) of the works of the Spanish enlightened seaman Jorge Juan y Santacilia (1713-1778),[20] we have been unable to trace another physical model of kite flying in the subsequent decades. Kites were at the frontier of several disciplines within physics, and it was not clear who could benefit from investigating them. Euler's analysis bridged the growing gap between experimental physics and practical mechanics:[21] the former studied general physical principles on experimental grounds; the latter constructed mathematical models of practical problems. However, as we will shortly see, experimental physicists benefitted little from Euler's model in the replication of Franklin's experiment. And in practical mechanics no interesting result was derived from the analysis of kites: they were simply unproductive.

Cerf – Volant dans ses Expériences électriques, & qu'annoblissant ainsi ce jouët il l´a introduit dans la Physique" (Euler, *Des Cerfs-volans* [cit. note 17], p. 322).

[19] Euler, Leonhard, "Recherches plus Exactes sur l´effet des Moulins à Vent," *Histoire de l´Académie Royale des Sciences et Belles Lettres, année MDCCLVI*, 1758: 165-234.

[20] In an appendix of his *Examen Marítimo* (1771), Jorge Juan analyzes the mechanics of the flight of kites with a view to verifying a theory of his own about the resistance exerted by a body immersed in a fluid. See Simón Calero, Julián, *The Genesis of Fluid Mechanics (1640–1780)* (Dordrecht The Netherlands, Springer, 2008), pp. 182-184.

[21] Frangsmyr, Tore, Heilbron, J. L. & Rider, Robin E. (ed.), *The Quantifying Spirit in the Eighteenth Century* (Berkeley: University of California Press, 1990).

Yet, the public taste for kites gave them an extra life as a tool for illustrating theoretical principles. They were embedded first in general reference works and then in popular science texts. Already in *L´Encyclopédie*,[22] the flight of a kite illustrates how to decompose the different forces involved, according to Euler's analysis. We find similar illustrations, for instance, in the *Lectures on Natural Philosophy and Mechanical Arts* (1807) by the British physician and physicist Thomas Young (1773-1829) and in the *Physikalisches Wörterbuch.*[23] Gradually, as the scientific interest of electrical kites faded, they migrated from these scholarly outlets to works aimed at general audiences: in the 1778 edition of Jacques Ozanam's *Récréations mathématiques et physiques*, revised by Jean-Étienne Montucla (1725-1799), we find an accessible version of Euler's analysis of the flight of kites. In the 19th century, we find the theory of flying kites in popular science textbooks such as John Ayrton Paris' *Philosophy in Sport* (1853), where Euler's approach gives way to standard applied physics. By the end of the century though, kites disappear even from these latter genre –e.g., Tissandier,[24] Good. As we will see in section 4, the popularity of kites as flying toys was decaying with the rise of aviation and they were not any more valuable as accessible illustrations.

The career of kites as theoretical objects of physics owed thus everything to Franklin's experiment, the real focus of public attention throughout the 18th and 19th century. It was this public success, we think, what gave electrical kites the temporary status of *scientific instruments*, as we read in *L'Encyclopédie*:

> Kite (Mechanics and Physics): we name as such a figure made of paper and wicker, that earlier served only as a toy for kids. They attached a string by means

[22] *L´Encyclopedie de Diderot et D´Alembert* (Redon, París, 2000).
[23] Gehler, Johann Samuel Traugott (ed.), *Physikalisches Wörterbuch. Zweiter Band C und D* (Leipzig: bei E. B. Schwickert, 1825-1845), pp. 583-591.
[24] Tissandier, Gaston, *Les Rècrèations Scientifiques ou L'Enseignement par les Jeux* (Paris: G. Masson Éditeur, 1887).

of which they flew it up in the air, when the wind was strong enough. But modern physicists have used it for attracting the electric fire from the clouds, so that the toy became in their hands an instrument of physics. This is why we discuss it here.[25]

Although rarely, we still find other discussions of electrical kites discussed as scientific instruments in specialized 18th century monographs, such as, for instance, Tiberius Cavallo's *A Complete Treatise on Electricity* (1782). Cavallo, an experimental physicist born in Italy and established in UK, became a real fan of electrical kites and discusses at length different variations on the basic setting, adding more iron pieces to the kite, using electrometer and, more decisively, insulating the string in order to make the whole device safe. The many conclusions that Cavallo drew from his numerous experiments are now justly forgotten: e.g., "The air appears to be electrified at all times; its Electricity is constantly positive, and much stronger in frosty, than in warm weather; but it is by no means less in the night than in the day-time."[26] However, Cavallo's attempts show that electrical kites lacked not only theoretical, but experimental productivity.

By the end of the 18th century, we find the first analytic laws about electricity and experimental devices aimed at the precise quantification of electrical phenomena.[27] If anyone had ever considered necessary to replicate Franklin's experiment, nobody else did at this point. However, unlike Euler's model, electrical kites survived as an

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[25] "CERF-VOLANT, (Méch. & Physiq.) on nomme ainsi une figure faite avec du papier & des osiers, qui ne servoit autrefois que de jouet aux enfans; ils y attachoient une ficelle, au moyen de laquelle ils l'élevoient en l'air, lorsque le vent étoit assez fort pour cela. Mais les physiciens modernes s'en sont servi pour tirer le feu électrique des nuées, ensorte que ce jouet est devenu entre leurs mains un instrument de physique ; & c'est par cette raison que nous en parlons ici" (*L´Encyclopedie* [cit. note 22]).

[26] Cavallo, Tiberius, *A Complete Treatise on Electricity* (London: 1782), pp. 370-394.

[27] Roche, John J., *The Mathematics of Measurement. A Critical History* (London, The Athlone Press, 1998), pp. 163-87 and Heilbron, John L., *Electricity in the 17th and 18th Centuries* (Mineola (N.Y.): Dover Publications Inc., 1999), pp. 449-489.

experimental setup in a number of scientific treatises.[28] Most are just simple restatements of the original experiment. But in the first decades of the 19th century they gradually disappear from every textbook.

Just as it had happened with their theoretical counterparts, in the 19th century electrical kites migrated from scientific treatises to the realm of recreational physics. We find it, for instance, in the catalogue published by the English instrument manufacturer John Cuthbertson (1743-1821), *Practical Electricity and Galvanism* (1821), where the safety of the device for the amateur experimentalist is properly highlighted. In the 1830s, the American *Franklin Kite Club* replicated for fun Franklin experiments with different types of kites[29]. And we find traces of other recreational replications till the end of the 19th century: the Swiss engineer Jean-Daniel Colladon (1802-1893) reports some in the journal *La Nature*[30] and the American meteorologist Alexander McAdie (1863-1943) reproduced the experiment with modern measuring devices in the Blue Hill Observatory in 1885. Again, as the public lost interest in kites, they disappeared as well from recreational physics.

Be it as a theoretical model or in an experimental setup, kites lacked scientific productivity, but in both cases they survived as recreational scientific objects for more than a century after Franklin's experiment[31]. We take this further career of kites as

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[28] For example see: Beccaria, Giambattista, *A Treatise upon Artificial Electricity* (London: J. Nourse, 1776), pp. 461-462; Bertholon, Pierre, *De L'electricité des Météores* (Paris: 1787), pp. 32-66 and Veau-Delaunay, Claude, *Manuel de L'electricité* (Paris, 1809), pp. 185-186.

[29] Abbe, Cleveland (1896), "The Franklin Kite Club," *Monthly Weather Review*, 1896, XXIV: 416.

[30] Colladon, Jean-Daniel (1887), "Expériences sur les Cerf-volant," *La Nature,* 1887, 15, (757): 97-98.

[31] A reviewer suggests an alternative interpretation for the fall of electrical kites (personal communication): "The status of kites in the 18th century could also be interpreted in terms of Enlightenment science: once the accepted standards of science changed at the end of the 18th century, those instruments which did not meet the newly established standards vanished into obscurity or were characterized as toys (the solar microscope could serve as an example in this respect)." This conjecture is certainly plausible and not contradictory with our own account, although we think we should emphasize productivity in the long-term story of scientific kites: even by the standards of 19th century science, kites failed to deliver new epistemic outcomes that might have given them a status within science.

evidence that it was more their popularity than their actual scientific interest what gave them a chance to briefly feature in the History of physics as either models or instruments. As to the causes of this popularity we can only guess: Van Riet's study of kites in 19th century British and American literature[32], for instance, documents at length how they came to represent our aspirations at controlling nature, be they successful or failed. E.g., in the short story *Sim Vedder's kite*[33] we find a very thin character (Sim Vedder) who is able to safely fly kites bigger than himself in a raging storm, thanks to the superiority of his designs: "didn't you ever hear of Dr. Franklin? We're doing just what he did", boasts Sim Vedder to his audience. As we will see in section 5, by the turn of the 19th century other flying artifacts would replace kites as symbols of control over nature.

3. Meteorological kites

But before we get to the origins of aviation, we should consider aerology, the field in which kites had their second chance to enter a scientific paradigm, this time as an elevator for a measurement device. Unlike electrical kites, the public plays here no role, but the whole process is driven by technological competition between different alternative tools. As we are going to see, this process transformed kites into a technological object very different from a toy and they were actually used in meteorological observatories in the first three decades of the 20th century. But despite this transformation, kites lost the competition and were abandoned by meteorologists as well.

[32] Van Riet, C.M., *The kite: A Symbol in Nineteenth-Century Literature*, RMA Thesis – Comparative Literary Studies, Utrecht University (2012). Available at http://igitur-archive.library.uu.nl/student-theses/2012-0820-200502/RMAThesis_CMvanRiet.pdf (accessed 24 April 2013).

[33] Sttodard, W. O., "Sim Vedder's Kite", *Harper's Young People,* 1880, I (25): 329-323. Available at: http://www.gutenberg.org/files/28790/28790-h/28790-h.htm#SIM_VEDDERS_KITE (accessed 27 April 2013).

Quantitative meteorology emerged by the late 18th century with thermometers and barometers accumulating data in networks of observatories established all over Europe. Gradually, it was conjectured that the climate was not a local phenomenon and could be predicted with a more global approach. In 1843, the invention of the telegraph would allow the communication of meteorological data quickly enough to feed more precise forecasts. In 1853 the first international conference on meteorology was hosted in Brussels, leading to a growing coordination of national weather services

The necessity of taking atmospheric measurements at high enough altitude in order to improve forecasts was soon perceived in these conferences. In 1896, an International Commission for Scientific Aeronautics was established[34]. The goal was to raise meteorographs to the higher layers of the atmosphere: these were instruments that could measure simultaneously pressure, temperature, relative humidity and wind direction. The data would allow meteorologists to draw synoptic charts where the measurements at different heights would be recorded. The reliability of the meteorograph depended thus on it being elevated steadily, without sudden rises or falls.

The obvious candidates to fly meteorographs aboard were kites and balloons. Balloons had already been used as an elevator for scientific instruments by the end of the 18th century[35]. Even if it was never used systematically as such, a few measurement instruments were designed for this particular use.[36] There is evidence as well of early uses of kites for atmospheric measurements:[37] in 1749, for instance, the Scottish astronomer Alexander Wilson (1714-1786) recorded the temperature at different

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[34] Friedman, Robert Marc, *Vilhelm Bjerknes and the Construction of a Modern Meteorology* (New York: Cornell University Press, 1989), p. 49.
[35] Lynn, Michael R., *The Sublime Invention: Ballooning in Europe, 1783–1820* (London, Pickering & Chatto Ltd, 2010), pp. 40-43.
[36] Middleton, W. E. Knowles, *Invention of the Meteorological Instruments* (Baltimore, The Johns Hopkins Press, 1969), pp. 288-289.
[37] Hart, *Kites* (cit. note 2), pp. 94-96.

altitudes with a set of kites tied to a single string, a *kite train*.[38] Balloons had certain advantages: you did not depend on the wind to use them and their ascent and descent was generally steady. But they were more expensive than kites.[39]

Hence, the measurement necessities of aerology created the incentives for designers to build more reliable kites. Kites were so transformed into relatively complex technological objects, different from the electrical toys of the previous century. On the 14th of September, 1847, for instance, the British astronomer William Radcliffe Birt (1804-1881), flew a specially constructed kite at the Kew Observatory: it was fixed in the air "by restraining it by means of three strings secured to the ground at the three corners of a comparatively large equilateral triangle."[40] Several more designs were tested,[41] but the more successful kite designs were those of William A. Eddy (1850-1909) and Lawrence Hargrave (1850-1915).

Eddy was an American journalist with a lifelong passion for kites, that he used for aerial photography.[42] Eddy started rising cameras at high altitudes (1200-1800 meters) with trains of even 16 flat kites. But these latter required stabilizing tails, quite prone to entanglements when the kites were mounted on a train. Eddy sought a tail-less design and found it in a Javanese kite, which he improved and patented in 1900. He stabilized the kite bending the horizontal stick in a dihedral angle (Fig. 3).

(Fig. 3 here)

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[38] Wilson, P. (1826), "Biographical account of Alexander Wilson," *Transactions of the Royal Society of Edinburgh*, 1826, X: 284-287.

[39] Kleinschmidt, Ernst (ed.), *Handbuch der Meteorologischen Instrumente* (Berlín: Verlag von Julius Springer, 1935), p. 474.

[40] Marvin, Charles F., "Kite Experiments at the Weather Bureau," *Monthly Weather Review,* 1896 April: 113-128, p. 114.

[41] For example see Archibald, E. Douglas (1884), "An Account of same Preliminary Experiments with Biram´s Anemometers Attached to Kite Strings or Wides," *Nature,* 1884, 31(786): 66.

[42] Eddy, William Abner, "Photographing from Kites," *The Century Illustrated Monthly Magazine,* 1897, 54, (1): 86-92.

In 1894, Eddy offered his kite to the Blue Hill observatory in Milton (Massachusetts USA), where they were mounted on trains that reached significantly high altitudes: a 10 kite train reached 7127 meters on May 5, 1910.[43]

Although patented, Eddy's kite was designed mostly by trial and error. Hargrave, a British engineer established in Australia, designed his kite from scratch inspired by the emerging field of aerodynamics. Interested in flying machines (about which we will see more in the next section), Hargrave was inspired by Wenham's 1866 idea that a configuration of two surfaces one above the other had more lifting power than a single one.[44] Hargrave built various types of kites to test it, of which the most stable turned out to be a configuration of two rectangular cells.[45] With further trials, he discovered that a curved surface gave his kite an even stronger lift force.

Unlike Eddy, Hargrave did not patent his kite. He just published it in the *American Engineer* in April 1895,[46] allowing other meteorologists to improve on his design, as many in fact did –for instance, Samuel A. Potter, Chales Frederick Marvin and Charles H. Lamson.[47]

By the end of the 19th century, meteorological kites were widely used in American and European observatories, mostly for measuring atmospheric pressure, temperature and relative humidity –for measuring wind speed and direction, balloons were preferred. The measuring device constitute by the meteorograph mounted on a train of Hargrave kites was certainly not a toy.

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[43] Hart, *Kites* (cit. note 2), p. 111.
[44] Hargrave, Lawrence, "Flying-machine Motors and Cellular Kites," *Journal of the Royal Society of New South Wales,* 1893, XXVII: 75-81, p. 78.
[45] Hargrave, Lawrence, "Cellular Kites", *Engineering*, 1893, Oct 27 (56): 523-524 and Hargrave, Lawrence, "On the Cellular Kite," *Journal of the Royal Society of New South Wale,* 1896, XXX: 144-147, Plate VII.
[46] Marvin, *Kite Experiments* (cit. note 40), p. 114.
[47] Marvin, *Kite Experiments* (cit. note 40), p. 115 and Henry, Alfred J., "A Weather Bureau Kite. How it is Constructed," *Scientific American Supplement,* 1826: 428-429.

These kites were built on a wooden framework, bolstered with wires. The sail of the lifting surface was made of very strong cotton cloth (Figure 4). These kites could thus resist the strong wind of the high layers of the atmosphere.

(Fig. 4 here)

The operation of such devices required qualified staff and at many observatories there was a *master kiter* in the payroll. Metereological kites remained in operation in most American and European observatories for around three decades, from the late 19th century until the 1930s.[48] They had several well-known limitations: if the wind broke the cable, apart from losing the instruments, the kite could become electrical and dangerous if it landed on power lines;[49] and the average altitude they reached was usually between 3000 and 4000 meters.

Other technologies soon provided competing alternatives. First, radiosondes mounted on balloons transmitted immediately the measurements even at higher altitudes. The rise of aviation made airplanes a more reliable and effective measurement base, despite their higher cost. Yet, by the 1930s meteorology could deliver predictions socially so relevant (for aeronautical traffic, for instance) to be worth the cost. Hence, kites disappeared as well from aerology, missing a second chance to become part (albeit secondary) of a scientific paradigm. Unlike electrical kites though, nobody referred to meteorological kites as scientific instruments. They played no epistemic role themselves, but were just an auxiliary device for the actual measurement tool, with competing alternatives (balloons) right from the beginning. The necessity to obtain

[48] Whitnah, Donald R., *A History of the United States Weather Bureau* (Urbana: University of Illinois Press, 1961); Dines, William Henry & Shaw, William Napier, *The Free Atmosphere in the Region of the British Isles* (London: Darling & Son, 1909) and Assmann, Richard, *Das Königlich Preussische Aeronautische Observatorium* (Lindenberg. Braunschweig: F. Vieweg & Sohn, 1915).
[49] Galbis, José, "Algo de Aerología," in *Congreso de Madrid, Tomo III Sección 2ª, Astronomía y Física del Globo,* edited by Asociación Española para el Progreso de las Ciencias (Madrid: Imprenta de Eduardo Arias, 1915), pp. 1-51.

reliable meteorological data drove this competition, transforming kites into a complex technological object, far from the toy it was only a century before.

4. Aeronautical kites

The third chance for kites to become scientific objects appeared too at the turn of the 20th century, with the beginning of aeronautical research. Boltzmann's words summarize the basic intuition of this approach: the dynamical principles sustaining a flying machine:

> [C]an also be exemplified by a well known toy –the kite. The same constitutes a large, slightly vaulted, and–because of an adherent tail– slightly inclined plane. If pulled quickly through the air on a twine, it ascends to a significant height.[50]

The physical analogy between kites and wings transformed kites into *scale models* for aeronautical engineering. In Euler's models, we had a mathematical representation of kites from which we made inferences targeting actual kites. Now, actual kites became physical models of actual wings: whatever worked in the former, should work in the latter. This is an inference from a physical artifact (the kite) to another physical artifact (the wing).[51] Engineers, architects and all sort of artisans traditionally tested this sort of inferences by trial and error.[52] In the 18th century we find the first traces of a more systematic procedure among engineers.[53] The ship models of

[50] Boltzmann, Ludwig, "On Aeronautics (1894)," in *Wittgenstein Flies a Kite* edited by Sterrett, Susan G., (New Yor: Pi-press, 2005): 255-264, p. 258.

[51] Sterrett, Susan G., "Similarity and Dimensional Analysis," in *Philosophy of Technology and Engineering Science. Handbook of the Philosophy of Science Volume 9*, edited by Meijers, Anthonie (Amsterdam: Elsevier, 2009), pp. 799-823.

[52] Müller, Roland, "The Notion of a Model: A Historical Overview," in *Philosophy of Technology and Engineering Science. Handbook of the Philosophy of Science Volume 9*, edited by Meijers, Anthonie (Amsterdam: Elsevier, 2009): 637-664, pp. 642-644.

[53] Zwart, Sjoerd D., "Scale Modelling in Engineering: Froude's Case," in *Philosophy of Technology and Engineering Science. Handbook of the Philosophy of Science Volume 9*, edited by Meijers, Anthonie (Amsterdam: Elsevier, 2009): 759-98, pp 764; Vincenti, Walter G., *What Engineers Know and How They Know it. Analytical Studies from Aeronautical History* (Baltimore: John Hopkins University Press, 1990),

the British engineer William Froude (1810-1879) set a standard for these material inferences, incorporating mathematical controls on the relevant variables, by which he tried to anticipate the behavior of the target artifact once the model was scaled up.[54]

Between the second half of the 19th century and the beginnings of the 20th, aeronautical researchers conducted two types of trials:[55] *direct trials* were those in which a full scale prototype of flying machine was tested; in *indirect trials*, the test was on a scale model. After Froude, it was clear that some sort of law was necessary to generalize from the scale model to the actual machine. But in aeronautical research no such law was available till the second half of the 20th century. In order to verify the results of the indirect trial, we needed a direct trial of the prototype.[56] Using kites as scale models of wings, the pioneers of aviation isolated several parameters of relevance and tested their models with different values in order to learn how they could expect their wings to behave in flight, before they tested their prototypes.[57] This method of variation of parameters was widely used in the early days of aeronautical research, giving kites their third chance as a scientific object.

Interestingly enough, this very empirical approach to modeling allowed these proto-aeronautical engineers to overcome the skepticism of physicists regarding flying machines. Flying presented a complicated theoretical puzzle: finding out which shape and size would make wings big enough to generate a high enough lifting force, with low resistance to the air. George Cayley[58] had already stated this problem at the beginning

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pp. 138-139 and Anderson, John D., *A History of Aerodynamics* (Cambridge: Cambridge University Press, 1997), pp. 126-130.

[54] Zwart, *Scale Modelling* (cit. note 53), p. 765.

[55] Zwart, *Scale Modelling* (cit. note 53), p. 770-772.

[56] Zwart, *Scale Modelling* (cit. note 53), p. 771.

[57] Vincenti, *What Engineers* (cit. note 53), p.139.

[58] Cayley, George, "On Aerial Navigation. Part I," *A Journal of Natural Philosophy, Chemistry, and the Arts*, 1809, 24, "On Aerial Navigation. Part II," *A Journal of Natural Philosophy, Chemistry, and the Arts*, 1809, 24, "On Aerial Navigation. Part III," *A Journal of Natural Philosophy, Chemistry, and the*

of the 19th century. In addition, there was the technological issue of designing an engine light enough to propel the machine, generate the necessary lift and steer it in the air. By 1850, there was a good description of the behavior of viscous fluids, the equations of Navier-Stokes, but it was also known that there was no analytical solution for a number of problems, among which the study of wings.[59]

However, since the 1750s, engineers had been trying to approximate the values of the variables controlling the behavior of machines propelled by fluids. In 1759, the British engineer John Smeaton presented an equation to calculate the force exerted by an air flow on the surface of a windmill blade, estimating the value of its parameter with a number of trials. This value remained virtually unquestioned till the tests of the Wright brothers in 1901.[60] In 1871, another British engineer, Francis Herbert Wenham built the first wind tunnel.[61] His colleague Horatio F. Phillips[62] used it to study whether flat or curved surfaces generated a bigger lift. With experiments of this sort, the engineers and the passionate amateurs organized in scientific societies (such as the Aeronautical Society of Great Britain, of which Wenham was a member) kept alive aeronautical research, almost completely abandoned at regular Departments of physics.[63]

Gliders were among the most researched flying machines during the 19th century. In 1804, the aforementioned Cayley built a scale model of a glider explicitly

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Arts, 1810, 25, in *Sir George Cayley´s Aeronautics 1796 – 1855* edited by Gibbs-Smith, Charles Harvard (London: H.M. Stationery Off., 1962), pp. 213-244.

59 Anderson, *A History* (cit. note 53), pp. 88-93.

60 Anderson, *A History* (cit. note 53), p. 76.

61 Hallion, Richard P., *Taking Flight* (New York, Oxford University Press, 2003), p. 117.

62 Phillips, Horatio F., "Experiments with Currents of Air," *Engineering*, 1885, 40: 160-161.

63 Anderson, *A History* (cit. note 53), p. 115.

inspired in a flat kite[64] (Fig. 5.1). Again, among the many designs he produced, in 1818 we find another kite-inspired one:

> A child's kite furnishes a good experiment on the balancing and steering of aerial vehicles, with a smaller one put the reverse way as a rudder stuck on by thick wire, so as to be set properly, and a weight to fasten to the middle stick till it will sail from the top of a hill slanting to the bottom, with perfect steadiness, obeying the rudder which should be turned a Little up, and oblique to either side the steerage is required: the bow of the large kite should be bent up thus [Fig.5.2b] by a bit of stick and a string. I have made surfaces of this kind carry down weights as high as 80 or go [lbs.] with perfect steadiness and steerage to either side at pleasure.[65]

Cayley ended up designing in 1852 the first aircraft in its modern sense:[66] the *Governable Parachute* (Fig.5.3), a glider to be launched from a balloon whose wings could be steered for controlling altitude and pitch.

(Fig. 5 here)

Together with sails and bird and bat wings, kites became a constant source of inspiration for aeronautical engineers. Laurence Hargrave, whose work we already examined in the previous section, tested in 1897 his *soaring kites*, aimed at simulating with their curved surfaces the wings of a bird. This curve, conjectured Hargrave,[67] allowed birds to glide without flapping their wings. Kites became here a scale model of an animal wing, and Hargrave varied systematically the shape, configuration and

[64] Gibbs-Smith, *Sir George Cayley* (cit. note 58), p.18.
[65] Gibbs-Smith, *Sir George Cayley* (cit. note 58), p. 85.
[66] Gibbs-Smith, *Sir George Cayley* (cit. note 58), p. 149.
[67] Hargrave, Lawrence, "The Possibility of Soaring in a Horizontal Wind," *Journal of the Royal Society of New South Wales* 1897, XXXI: 207-213.

surface of the kite, as well as its weight, in order to find out which particular values made it glide facing the wind, as birds did.[68]

Between 1866 and 1889, the German engineer Otto Lilienthal conducted a series of trials with gliders showing the superior lifting power of curved wings. Following the same inspiration than Hargrave, in September 1874 Lilienthal[69] build a curved kite imitating the wings of gliding seabirds. He controlled it with two strings in order to show that gliding depended on the "skillful direction of wings".

The French-American engineer Octave Chanute run his own series of trials with kites, in collaboration with Augustus M. Herring. In 1895, Herring built and tested the *ladder kite*, seeking a combination of surfaces that maximized equilibrium. Once found, Chanute and Herring designed a glider with six sets of superimposed wings.[70] Here we have an analogical inference from the scale model to the prototype. Another instance can be found in the curved kite with a tail stabilizer tested by Herring as a preliminary step towards their biplane glider with a cruciform tail.[71]

The winners in this race for making a machine fly, the brothers Wilbur and Orville Wright, drew on all these results in designing and implementing their own control system for gliders. And again, in august 1899 they run an indirect test with a biplane kite. This was basically a Hargrave cellular kite with curved surfaces, in which the cells were not closed.[72] They stabilized it instead with four controlling strings operated from earth: pulling these strings, the Wright brothers generated a wing-

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[68] Hargrave kites actually inspired a series of gliders and aircrafts: those of the brothers Voisin and Alberto Santos-Dumont, for instance. Gibbs-Smith, Charles Harvard (1960), *The Aeroplane: An Historical Survey* (London: H.M. Stationery Off., 1960), pp. 52-54.

[69] Lilienthal, Otto, *Birdflight as the Basis of Aviation* (Hummelstown, Markowski International Publishers, 1889/2001), pp. 90-94.

[70] Scamehorn, Howard L., *Balloons to Jets: a Century of Aeronautics in Illinois, 1855-1955* (Chicago, Southern Illinois University, 2000), p. 27.

[71] Gibbs-Smith, Charles Harvard, *The Invention of the Aeroplane* (London: Faber, 1966), pp. 28-30.

[72] Hart, *Kites* (cit. note 2), p. 151.

warping in the kite. This technique allows the lateral control of the kite, that they expected to reproduce in the glider's wings.

Between 1900 and 1902, the Wright brothers tried different glider prototypes making them fly as kites in order to test the control system and the lifting force of the wing shape. This is how they found out that Lilienthal's estimates of the lifting force of a curved wing did not work in their own design,[73] proceeding to new trials in a tunnel wind[74] that ended up in a new wing shape. In 1902, they successfully tried a glider controlled on three different axes.[75] For pitch control, the Wrights used an all-moving elevator at the front of the aircraft. The roll control was provided by wing-warping. In the 1901 trials, the Wrights identified the need for a rudder at the rear of the aircraft to control yaw.[76] At the suggestion of Chanute, the Wright brothers spent the following year working in an engine.[77] On September 17, 1903, the Wright brothers successfully tried their *Flyer I*, a prototype of a self-propelled and controlled flying machine.

All in all, kites can take credit for this success, since they proved to be adequate scale models for glider wings. Its adequacy though was only practically shown, since from a purely theoretical perspective, the physics of these models was not well understood. Yet, the success of the Wright brothers prompted scholars and engineers to grasp what they did and in the first decade of the 20th century we find a number of

[73] Wright, Orville, *How We Invented the Airplane. An Illustrated History. Edited, with an Introduction and cCommentary by Fred C. Kelly* (New York, Dover Publications, Inc, 1953), p.15.
[74] Anderson, John D., *The Airplane. A History of its Technology* (Reston (VA): American Institute of Aeronautics and Astronautics, 2002), pp. 105-111.
[75] An aircraft must be controlled on three principal axes: an up and down movement of the nose, that is called *pitch*; a side to side movement of the nose, the *yaw*, and an up and down movement of the wing tips, the *roll*.
[76] Anderson, *The Airplane* (cit. note 74), p. 127.
[77] Anderson, *The Airplane* (cit. note 74), pp. 118-123.

theoretical models of wings[78] that successfully contributed to the design of new prototypes in the coming decades.[79]

In 1914, the American physicist Edgard Buckingham proved his Theorem-Π which gave rise to dimensional analysis.[80] According to Buckingham, every physical system is defined by a number of independent variables. If we wanted to experimentally test the dependence of one of these variables on the others, we would need a long series of trials in which each potential dependence is explored, keeping the remaining variables constant. Theorem-Π allows us to transform them into groups of dimensionless variables, whose behavior we can anticipate on purely mathematical grounds.

Hence, in less than two decades, the testing of scale models for wings was put under theoretical control: a better understanding of the physical foundations of wings, on the one hand, and a more solid grasp of the geometrical analogy between them and their scale models, on the other, yielded a more efficient use of dimensional analysis to control indirect trials in wind tunnels.[81]

Despite the efforts of late day enthusiasts, such as Alexander Graham Bell,[82] kites quickly vanished from aeronautical research. Not for lack of success, as we just have seen, but because they simply could not stand competition this time with more theoretical approaches to scale model testing.

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[78] Kármán, Theodore von, *Aerodynamics: Selected Topics in the Light of Their Historical Development* (New York: Courier Dover Publications, 1954), pp. 31-58.
[79] Anderson, *The Airplane* (cit. note 74), pp. 132-182
[80] Sterrett, *Similarity and Dimensional* (cit. note 51), p. 818-821.
[81] Zwart, *Scale Modelling* (cit. note 53), pp. 769-780 and Sterrett, *Similarity and Dimensional* (cit. note 51), p. 801.
[82] Parkin, J. H., *Bell and Baldwin* (Toronto: University of Toronto Press, 1964).

Conclusion: The complementary science of kites

In *Inventing Scientific Temperature* (2004), Hasok Chang defends the thesis that History and Philosophy of science (HPS) can be appraised as *complementary science*: "Complementary science asks scientific questions that are excluded from current specialist science", claims Chang.[83] In other words, HPS would study objects that were abandoned by science, left aside by the successful paradigms, and see what they teach us about our current knowledge. According to Chang, the study of forgotten scientific phenomena (such as water not boiling above 100º, a real and well-documented phenomenon in 19th century physics textbooks) would allow us to grasp the boundaries of current scientific knowledge, enhancing our *critical awareness* of its limits.

The study of scientific kites from a HPS perspective would also allow us to enhance our *trust* in science, since in all cases it seems as if science actually exhausted their epistemic potential. Kites, let us recall it once more, did not lead to scientific error: Franklin's experiment was correctly replicated; kites delivered reliable aerological observation and successful scale models of wings. Even in rational mechanics, Euler's models were as good as those of any other hydraulic machine. However, in every case, kites lacked *productivity*:[84] either they yielded no further results (as it was the case with electrical kites) or they were soon replaced by more efficient alternatives (as in aerology and aeronautical research). Hence, kites were not left aside by science with a reservoir of epistemic potential yet to be exploited. Franklin's experiments have been replicated with different types of kites and instruments without further discoveries.[85] Current fluid mechanics can retrieve every insight contained in Euler's models. Balloons and then

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[83] Chang, Hasok, *Inventing Temperature*. *Measurement and Scientific Progress* (New York: Oxford University Press, 2004), p. 3.
[84] Daston, *Biographies* (cit. note 6).
[85] McAdie, Alexander George, "Flanklin´s Kite Experiment with Modern Apparatus," *Popular Science Monthly*, 1897, Oct., 51: 739-747.

airplanes provided convergent aerological measurements and we can now reanalyze the flight of kites as wings from both a theoretical and experimental perspective.[86] In sum, scientists abandoned kites for good epistemic reasons.

However, science left an imprint on kites: their design, materials and construction is in debt with 160 years of scientific tests (starting with the isolation of the string in electrical kites to the implementation of curved shapes in aeronautical research). We can see it still in the kites used now as sails in big tankers or in the recreational models used in kite-surfing (Fig. 6).

(Fig. 6 here)

If nobody finds new epistemic potential in kites, they will remain the toys documented in the Oxford English Dictionary. However, in the words of Gerard L'E Turner,[87] rather than simple toys, kites are now a *scientific toy*, although most of those who enjoy them may never notice it.

Figures

Fig. 1. Some exemplary instances of Franklin's kite experiment (1) Commemorative stamp of Franklin's 250 anniversary (2) Silver dollar commemorating his 300th anniversary in 2006 (3) 1953 advertisement of the Chase Brass and Copper Company Inc. (4) 1939 advertisement of the whiskey brand *Haig & Haig Five Star Pinch Scotch* (5) Franklin themed beer jar (Source: author's private collection).

Fig. 2. (1) Engraving of Romas' experiment in Romas, Jacques de, *Mémorire, sur les Moyens de se Garantir de la Foudre dans les Maisons* (Bordeaux, 1776). **(2)** Engraving of Romas' electrical cart in Brisson, Mathurin Jacques, *Dictionnaire Raisonné de Physique* (Paris: Thou, 1781-1800). **(3)** Engraving of the French magazine *La Nature* (1877), describing Roma's experiments. Girard, Maurice, "Les Manieurs de Foudre," *La Nature*, 1877, 191, *27 Janvier*: 134-137.

Fig. 3. Eddy's kite train in the Blue Hill observatory. Clayton, H. H., "The Eddy Malay Tailles Kite," *Scientific American*, 1894, September, 15: 169-170, 1894, p. 169.

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[86] Dawson, Ross Hughan, *Kite Turning.* Thesis, University of Canterbury (New Zealand, 2011). Available at http://ir.canterbury.ac.nz/handle/10092/5475 (accessed 27 April 2013).

[87] Turner, Gerard L'E., "Scientific Toys," *The British Journal for the History of Science,* 1987, 20, (4): 377-398.

Fig. 4. **(1**) Hargrave's kite in Rotch, Lawrence, *Sounding the Ocean of Air* (New York, E & J. B. Young & Co, 1900), p.130. **(2)** Meteorological *Marvin-Hargrave* kite used by *U.S. Weather Bureau* (Source: author's private collection).

Fig. 5. Cayley's gliders: (1) 1804. (2) 1818. (3) *Governable Parachute* (1852) in Gibbs-Smith, *Sir George Cayley* (cit. note 63), pp.17, plate II, 85, 151.

Fig. 6. Kite-surfing in Punta Taloma, Tarifa (Spain), © Manuel González Olaechea y Franco (http://upload.wikimedia.org/wikipedia/commons/0/05/Kitesurfing.JPG).