Airborne Wind Energy

History of kite applications

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TU Delft

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Outlines

- Early history
- Middle ages
- Enlightenment
- Golden Age of Kites
- Aerial photography
- Meteorology
- Precursor for powered flight
- Rediscovery for power generation
- Rediscovery for sports
- Airborne wind energy
- Homework
- References



Kitepower

Learning objectives

- Understand for what purposes and how kites were used **in the past**
- Assess the technical advancements during the **Golden Age of Kites**
- Develop an overview of the **AWE sector** and understand what the different academic and industry players are working on
- Identify **differences** and **similarities** between past and present use of kites

Early history



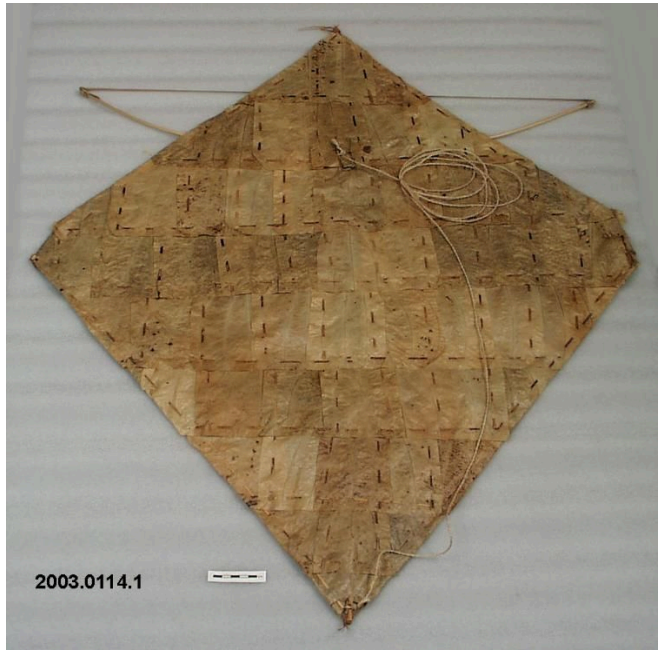
Simon Christen/Flickr

Use of kites in the past

- **Religious:** to offer up wishes to the gods of weather and crop fertility at the time of spring planting or at fall harvest; or to just appease the spirit world.
- **Utilitarian:** to carry fishing line and hook out over the water in atolls, thus providing a means of catching fish in somewhat remote water from where the fisherman stood.
- **Cultural:** to demonstrate artistically the symbols of a region or nation in the sky.
- **Military:** to visually signal other troops, scatter messages over the enemy, measure distances, training targets, and as kite technology improved to lift observers over military areas.

Origin of kites

- The precise origin of the kite is obscure, however scholars believe it was developed either in China, Malasia, Indonesia or the South Pacific Islands (Polynesia).
- A possible but controversial early finding is the kite painting in an Indonesian cave:



Kolope leaf kite



Cave paintings on Muna island, off the island of Sulawesi, 9000-5000 BC



Painting of a person holding a leaf kite

Exhibit: Canada Aviation and Space Museum, Cave paintings: Tari Travel

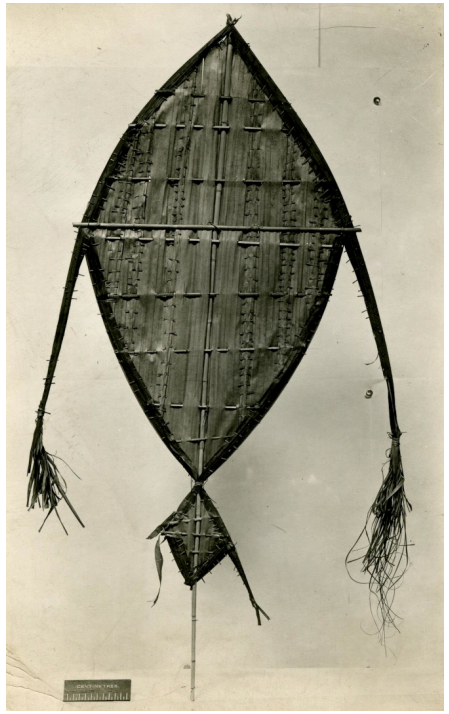
Early use of kites

- The fishing peoples of the South Sea islands used kites for fishing by attaching bait to the tail of the kite and using a net to catch the fish. A practice that continues in the Solomon Islands.
- On the Polynesian Islands a kite represented the god Tane, as well as the god Rongo who was the patron saint of the arts, kites, and kite flying. Sometimes, the kites represented the gods themselves. Kite flying was considered a sacred ritual.
- Polynesian folklore records many incidents where kites have been a means of making contact with the heavens. Kites often symbolized gods or have been the toys of the gods. In many cases, Polynesian kites were associated and constructed in the configuration of the wig birds. In early times, turtles, human figures, and abstract shapes were also known.
- The Maori in what is now known as New Zealand believed that birds could carry messages between humans and gods. The Maori god Rehua is depicted as a bird, and was thought to be the ancestor of all kites.

Polynesian fishing kites

Materials:

- Wood, rushes, feathers, and shells, which produced a rattle in flight.
- Thin strands of vine or braided fibers for flying/tethering line.
- A native bark cloth (tapa), leaves, and braided reeds were used for sail material.



Fishing kite from Vanuatu



Fishing kite from Papua New Guinea



Fishing kite from Solomon islands

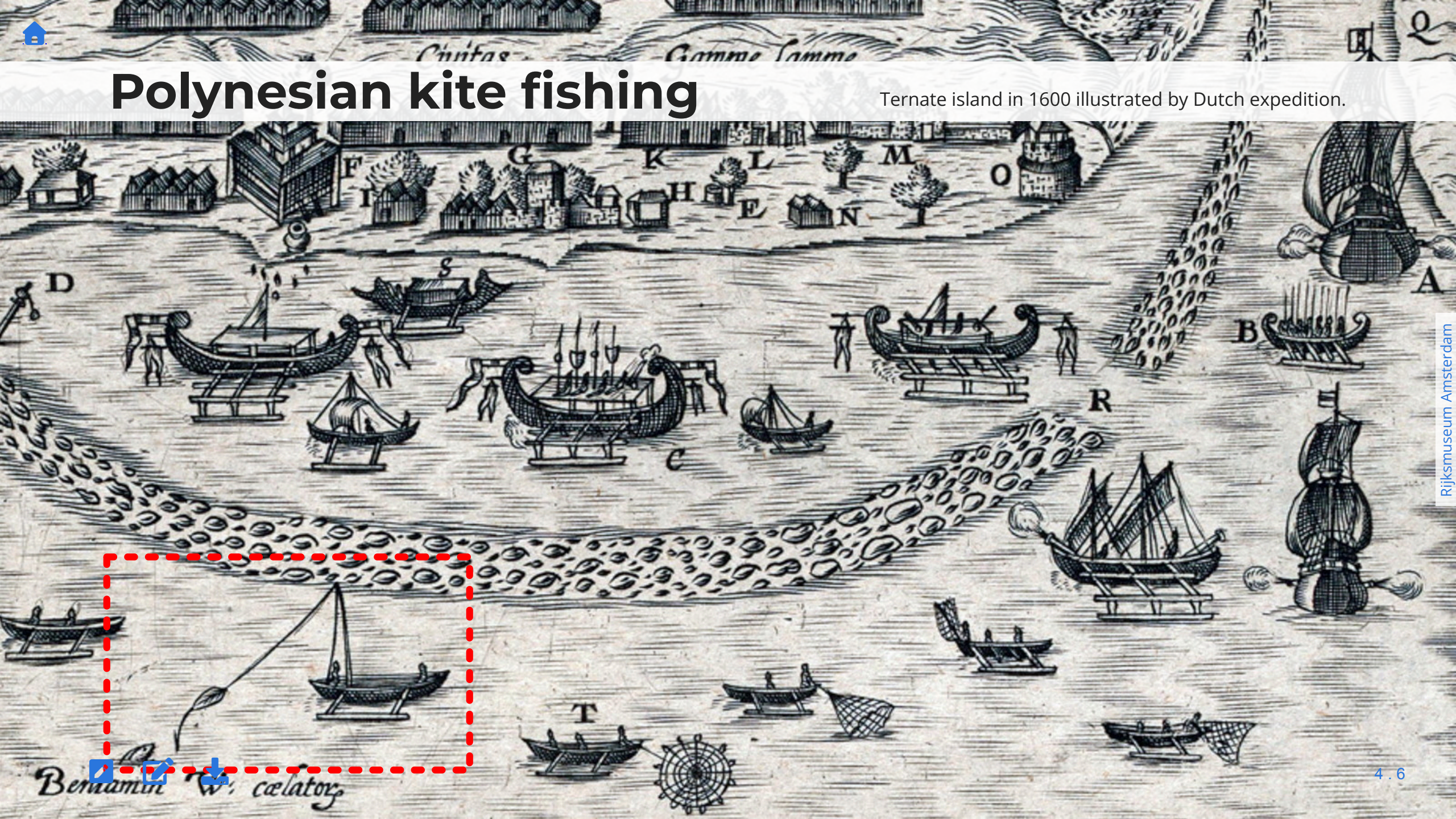


Kites in Polynesia

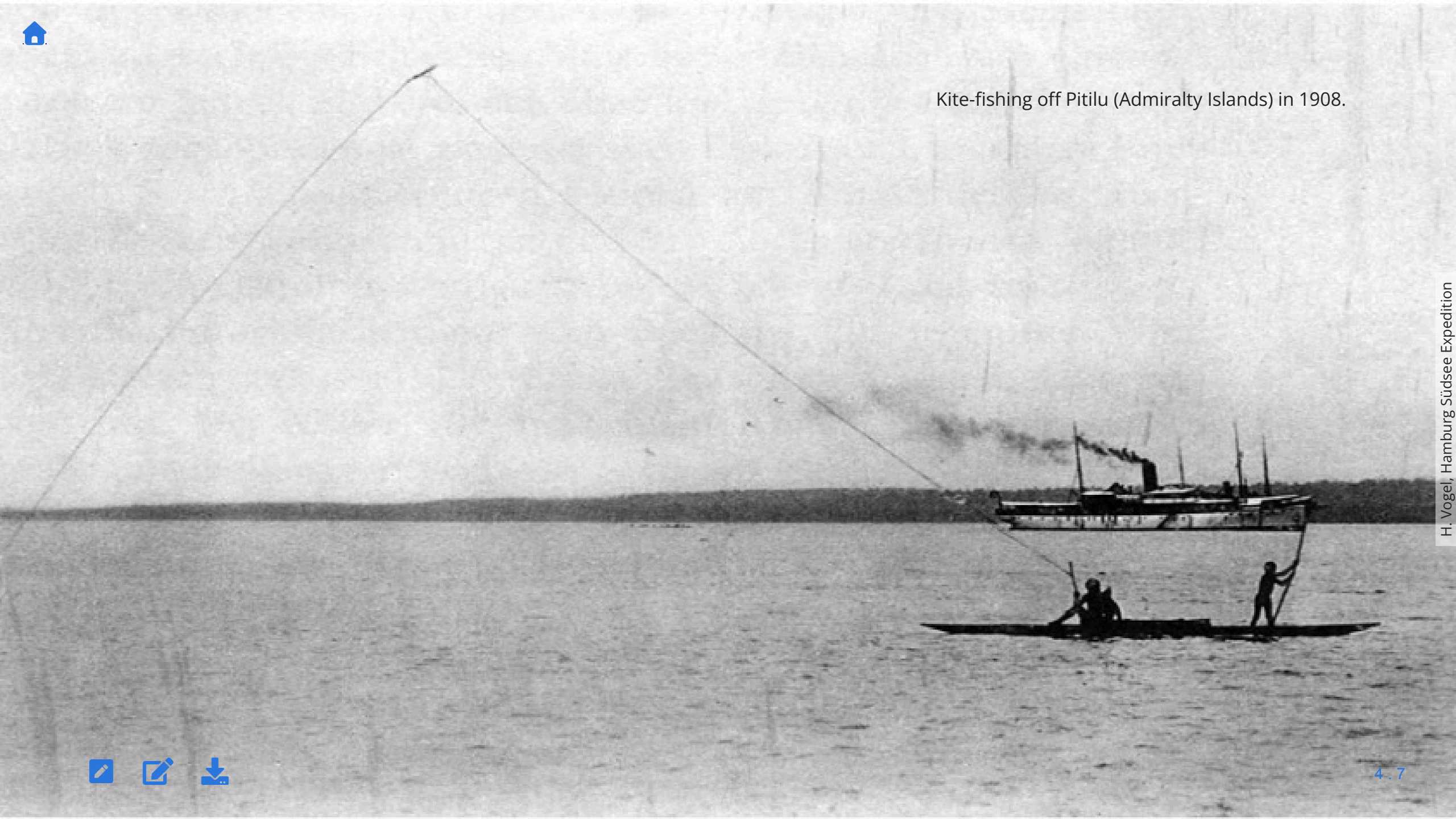
British Museum: left, center, right.

Polynesian kite fishing

Ternate island in 1600 illustrated by Dutch expedition.



Rijksmuseum Amsterdam



Kite-fishing off Pitilu (Admiralty Islands) in 1908.

H. Vogel, Hamburg Südsee Expedition

Maori kites

Collected in 1843 in the Bay of Plenty on the North of the Island of Aotearoa, New Zealand, this kite was made within the tradition of kite flying for spiritual purposes.



British Museum

Chinese kites

- Approx. **502-549 BC**: During the time of LiangwuDi Emperor, a kite was used with limited success to send messages.
- Approx. **468-376 BC**: Historical records mention the famous Chinese philosopher Mo-tse (Mo Ti in some texts) as the first to build a kite. Living near Mt. Lu, in the area of Qingzhou, Shandong province (near present day Weifang China), Mo-tse carefully carved a bird (a ‘sparrow hawk’ or eagle) over a period of three years. Once satisfied that it was as much like a bird as he could make it, he flew it for only a single day. The exact Chinese traditional kite details of its flight are not recorded, but there is conclusive, written reference to this event in Chinese history.
- Approx. **200 BC**: In the Han Dynasty, General Han Xin used a kite as a tool to determine how far his army would have to dig to get under the castle wall.
- After the invention of paper **AD 105**: Kite building and flying became a popular pastime.

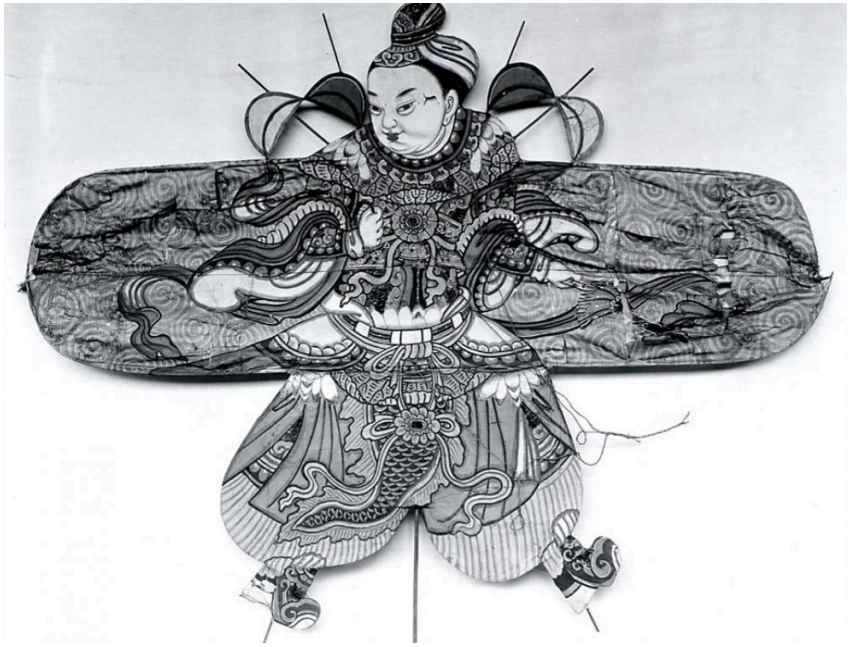
Chinese kites

Materials:

- Bamboo or similarly strong reed like branches for framing structure. Thin strands of vine or braided fibers for flying/tethering line.
- Woven cloth and later paper, were commonly used for sail material.



Kite Flying by Suzuki Harunobu (1766)



Chinese Kite (1932)



Kite made in the traditional wooden bird design

Left: Metropolitan Museum of Art, center: Smithsonian Museum, right: PBS Learning Media

Further reading

- Nora K. Chadwick: The Kite: A Study in Polynesian Tradition. The Journal of the Royal Anthropological Institute of Great Britain and Ireland, Vol. 61, pp. 455-491, 1931.
- Damion Sailors: Manu - An Analysis of the Ancient Practice of Oceanic Kite-flying. In: 78th Annual Meeting of the Society for American Archaeology, Honolulu, HI, USA, 3-7 April 2013.
- Stefan Dietrich: Flying a kite and catching fish in the Ternate panorama of 1600“. The Journal of the Hakluyt Society, August 2012.
- George Webster: The Invention of the Kite. The Kiteflier, Issue 98, 2004.

Middle ages



Marco Polo's Caravan, Catalan Atlas, 1375

Arrival of the kite in Europe

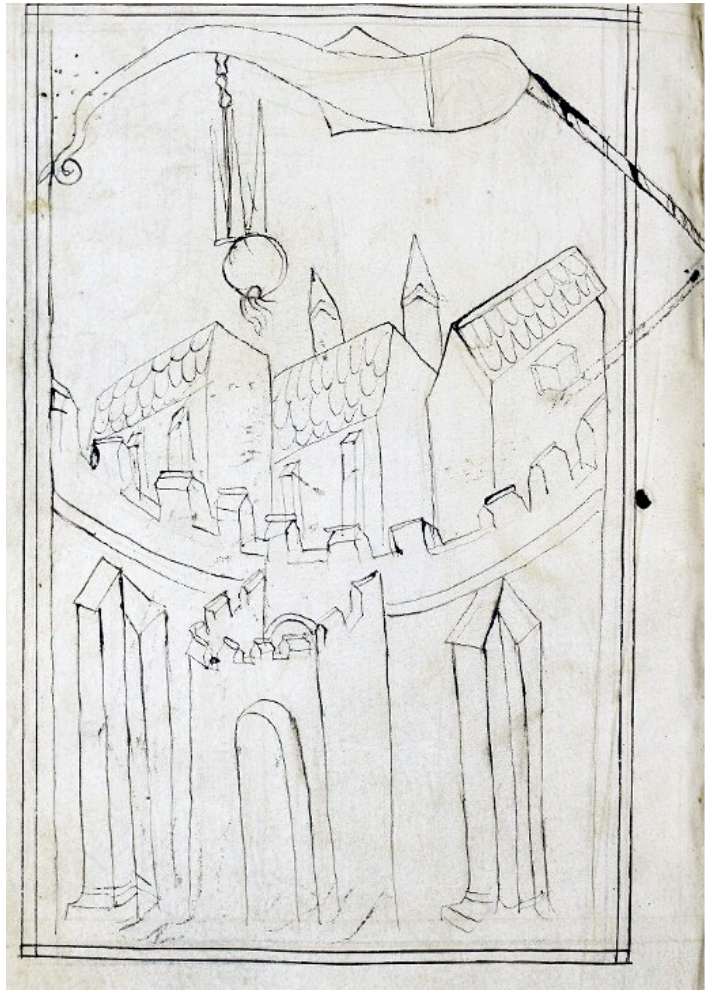


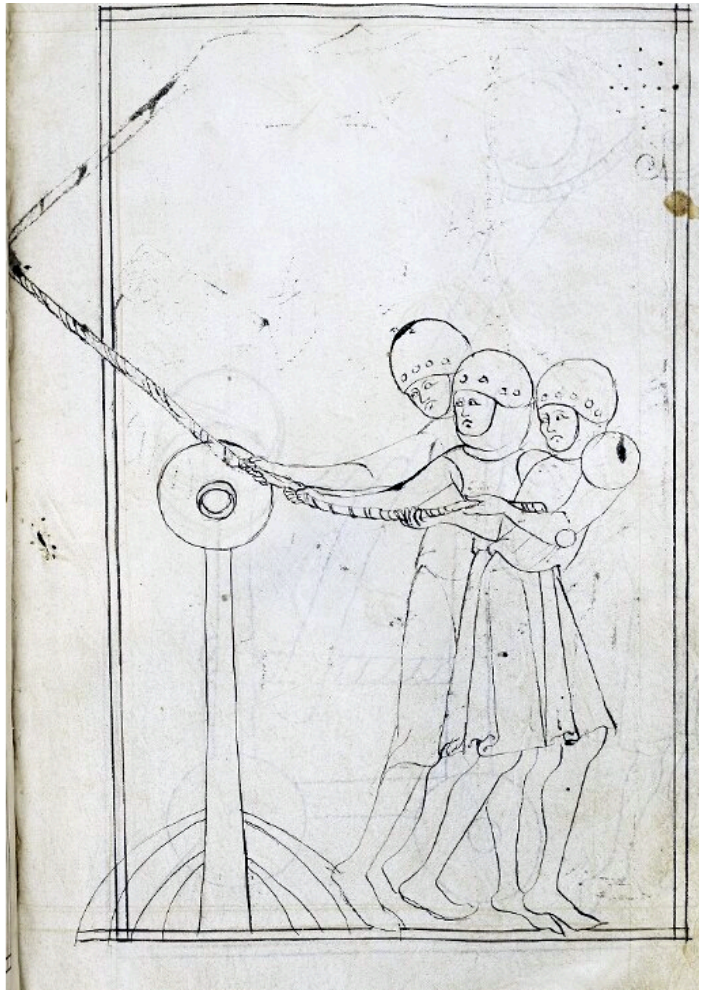
Marco Polo (1254-1324)

- By the 13th century, kite flying had spread by traders from China to **Korea** and across Asia to **India** and the **Middle East**. Each region had developed a distinctive style of kite and cultural purpose for flying them.
- The **Greek** already knew kites around the 4th century BC.
- In the late 13th century, European explorer, **Marco Polo**, describes in his book from **1295** kites and their man-lifting capabilities after seeing Chinese merchants using kites to determine whether a voyage would be prosperous or not.
- Kite flying spread throughout Europe between 14th and 15th centuries with mentions by Vasco da Gama, Giovanni Della Porta, and William Shakespeare.
- Sailors also brought kites back from **Japan** and **Malaysia** in the 16th and 17th centuries. Kites were regarded as curiosities at first and had little impact on European culture.

Mosaic of Marco Polo displayed in the Palazzo Doria-Tursi, in Genoa, Italy (1867).

Use for warfare





Sketch in De nobilitatibus, sapientiis, et prudentiis regum,
by Walter de Milemete (1326)



Rider with a dragon kite, in Bellifortis,
by Konrad Kyeser (~1405)

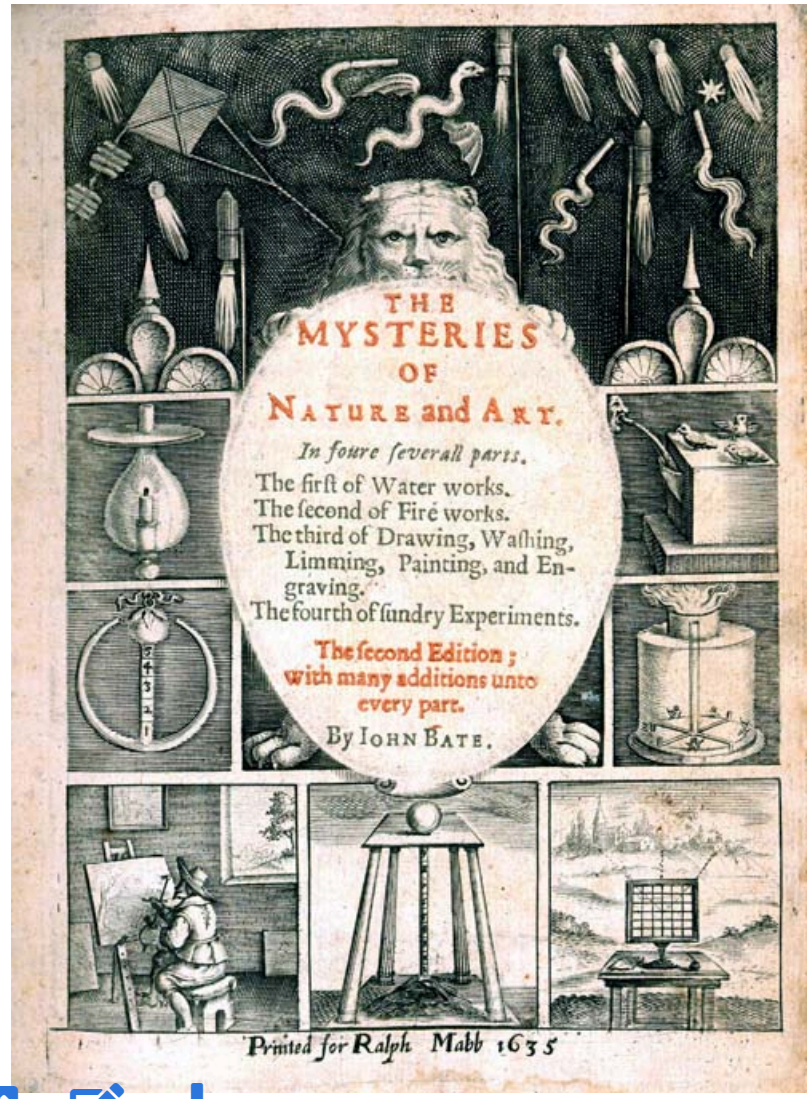
Renaissance of 15th & 16th centuries

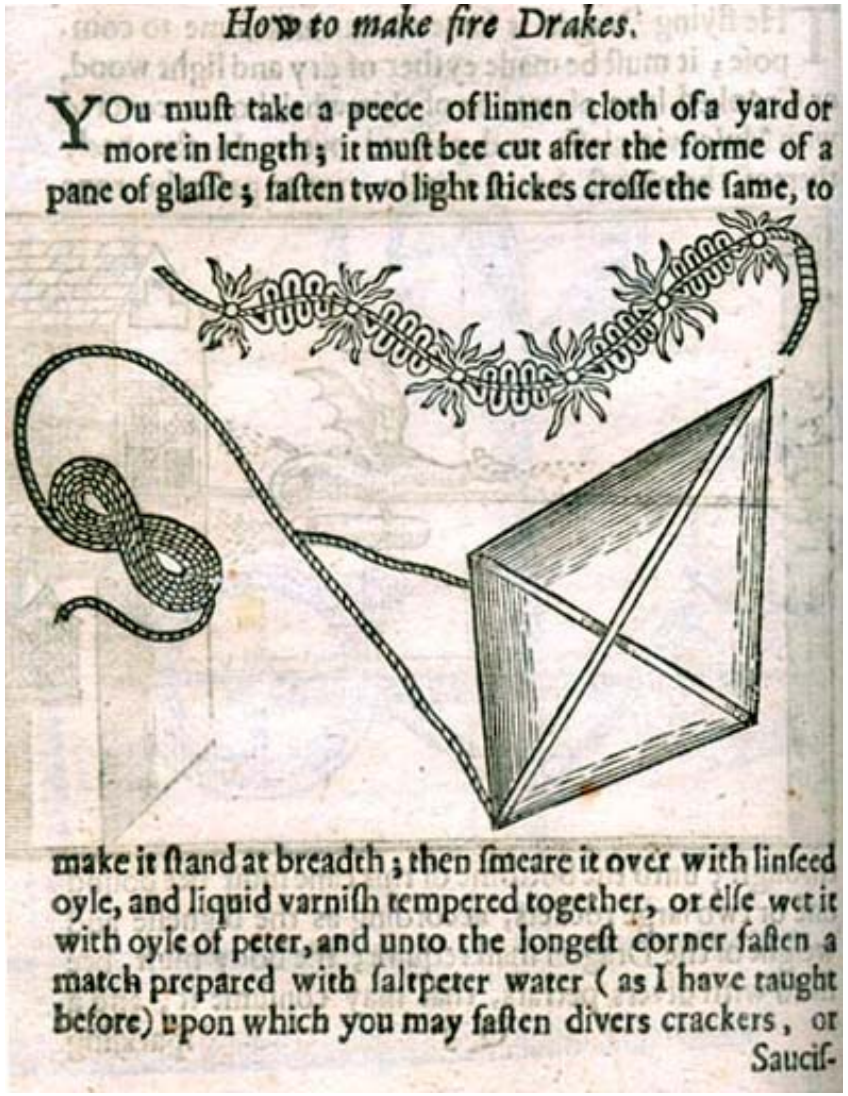


John Bate

- Period in European history marking the transition from the Middle Ages to modernity.
- A spirit of initiative and invention lead to significant advances in mechanics, chemistry and metallurgy, astronomy and surveying, the art of navigation, and the measurement of time.
- The Mysteries of Nature and Art was written by **John Bate** in **1634** as a practical guide for amateur scientific experiments.
- It inspired Isaac Newton during his younger years, in particular the section on **fire Drakes**, kites with firecrackers tied to their tails.
- It contains one of the earliest depictions of fireworks and their preparation to be detailed in the English language, in a similar manner to the preceding De la pirotechnia

The Mysteries of Nature and Art





The Mysteries of Nature and Art, by John Bate (1635)

Detail from page 118: how to make fire Drakes

Further reading

- Peter Konieczny: The History of Flying in the Middle Ages.
- The Art of Kite Flying (1430–1929). Collections/Images, The Public Domain Review, 17 June 2026.

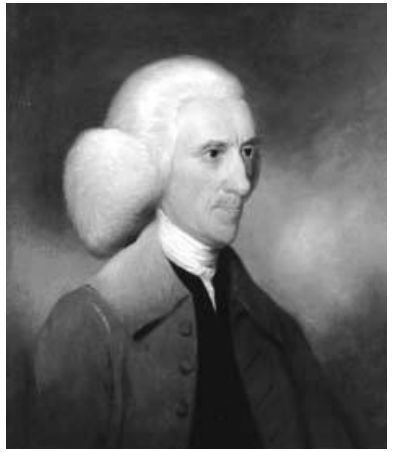
Enlightenment

Scientific and technical explorations (1750–1860)



Rainer Knäpper, Free Art License

Meteorology



Alexander Wilson (1714-1786)

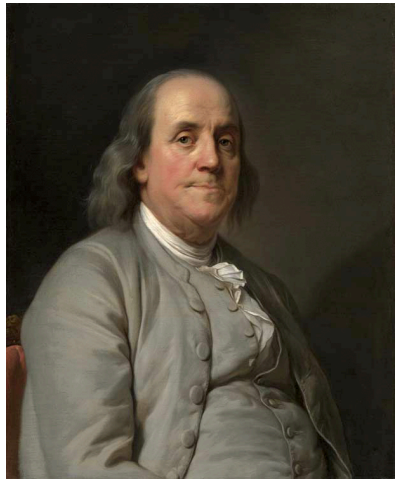
- First recorded weather experiments with kites were performed in **1749** by two University of Glasgow students, **Alexander Wilson** and **Thomas Melville**.
- Their interest was the possible **temperature variation** in the atmosphere and at the time, kites were the only means to access higher altitudes.
- The scientists built **six paper kites**, each carrying a small **thermometer** protected by layers of cloth.
- Each payload had a **slow burning fuse** and a **white ribbon** attached.
- The fuse allowed a **timed separation** of the payload from the kite.
- The white ribbons **decelerated** the falling payload and **signaled** to the scientists.
- This experiment was the first recorded attempt to collect **scientific data** with kites and to use a **train of kites**.

Robinson (2003)

Hunterian Art Gallery, University of Glasgow.

Electricity

- **Benjamin Franklin** published a proposal for an experiment to prove that **lightning is electricity** by flying a kite in a storm that appeared capable of becoming a lightning storm.
- On 15 June **1752**, he may possibly have conducted his well-known kite experiment in Philadelphia, successfully extracting **sparks from a cloud**.
- Franklin described the experiment in the Pennsylvania Gazette on 19 October 1752, without mentioning that he himself had performed it.
- This account was read to the Royal Society on December 21 and printed as such in the **Philosophical Transactions**.
- Franklin was careful to stand on an insulator, keeping dry under a roof to avoid the danger of electric shock.



Benjamin Franklin (1706-1790)

Smithsonian's National Portrait Gallery

Benjamin Franklin Drawing Electricity from the Sky is a 1816 painting by Benjamin West depicting the American founding father conducting his kite experiment in 1752 to ascertain the electrical nature of lighting.



Worlds oldest known kite

- **French Pear Top** kite from **1773**.
- Discovered by a carpenter when lifting the attic floor during the renovation of a building at 127 Breestraat, Leiden, the Netherlands in 1985.
- Paper covering and sticks made of hazel wood.
- 930 mm along the spine, 630 mm wide, in flyable condition.
- Purchased and restored by Peter Lynn.

Video player configuration error

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Watch video on YouTube Learn more

Error 153

Restoration of the worlds oldest known kite, by Peter Lynn.



Context (1785)

First Channel crossing by hot-air balloon by Blanchard and Jeffries.



Science Museum Group Collection

Engineering



George Pocock (1774-1843)

- George Pocock was a schoolteacher in Bristol experimenting with **man-lifting kites** starting in 1820.
- In 1826 he patented the design of the **Charvolant**, a buggy that was pulled by two kites on a single line of 457–459 m.
- Four **control lines** to the kites, which were fed out or pulled in by large **spools** mounted on the front of the carriage, provided a method of steering.
- The driver also had to **steer the carriage** by means of a T-bar which set the direction of the front wheels.
- The driver also was responsible for the **brake**, an iron bar mounted on the carriage which dug into the road when the lever was pulled.
- Average travel speed with several passengers was **32 km/h**.
- On a joint trip of **182 km**, one of the three participating Charvolants sailed past the mail coach, which at the time was the fastest means of passenger transportation.
- Initial successes because technology was **circumventing taxation** of horse-powered carriages, however, ultimately too complex to survive.

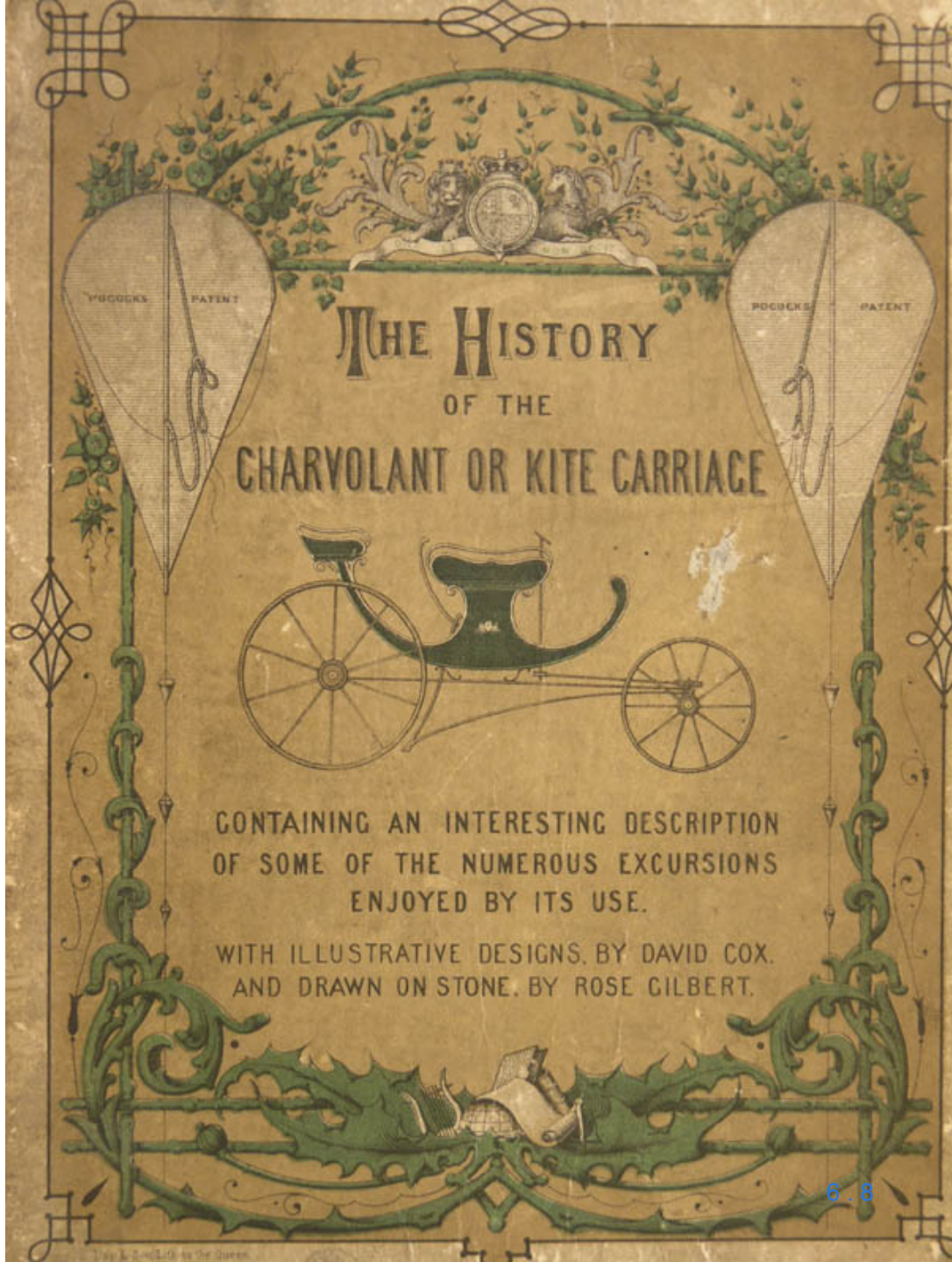
Pocock's book

G. Pocock: The Aeropleustic Art or Navigation in the Air by the use of Kites, or Buoyant Sails. London: W. Wilson, 1827.

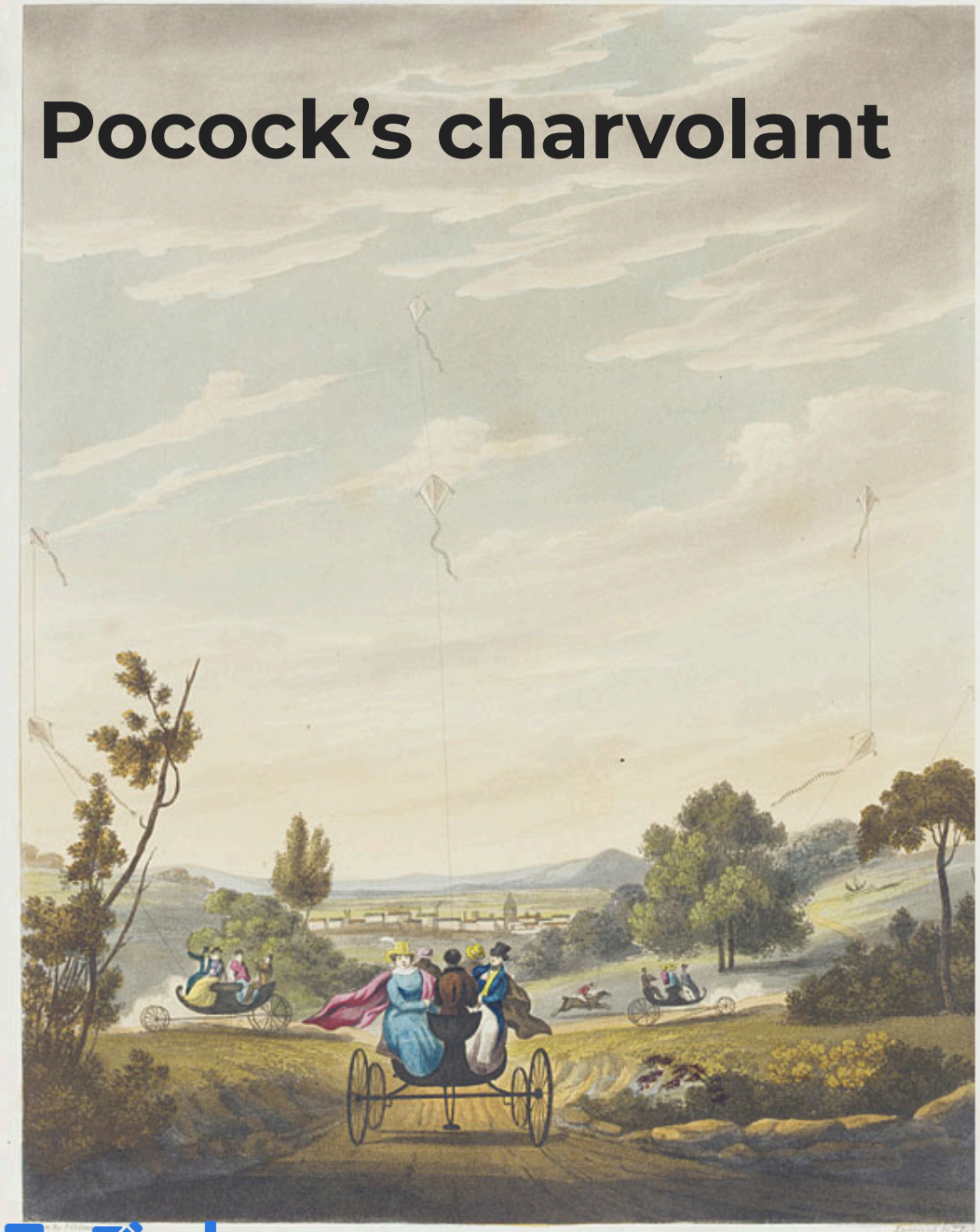
G. Pocock, D. Cox, R. Gilbert: A treatise on the æropleustic art, or, Navigation in the air : by means of kites, or buoyant sails. London: Longman, Brown, and Company, 1851.

Also in:

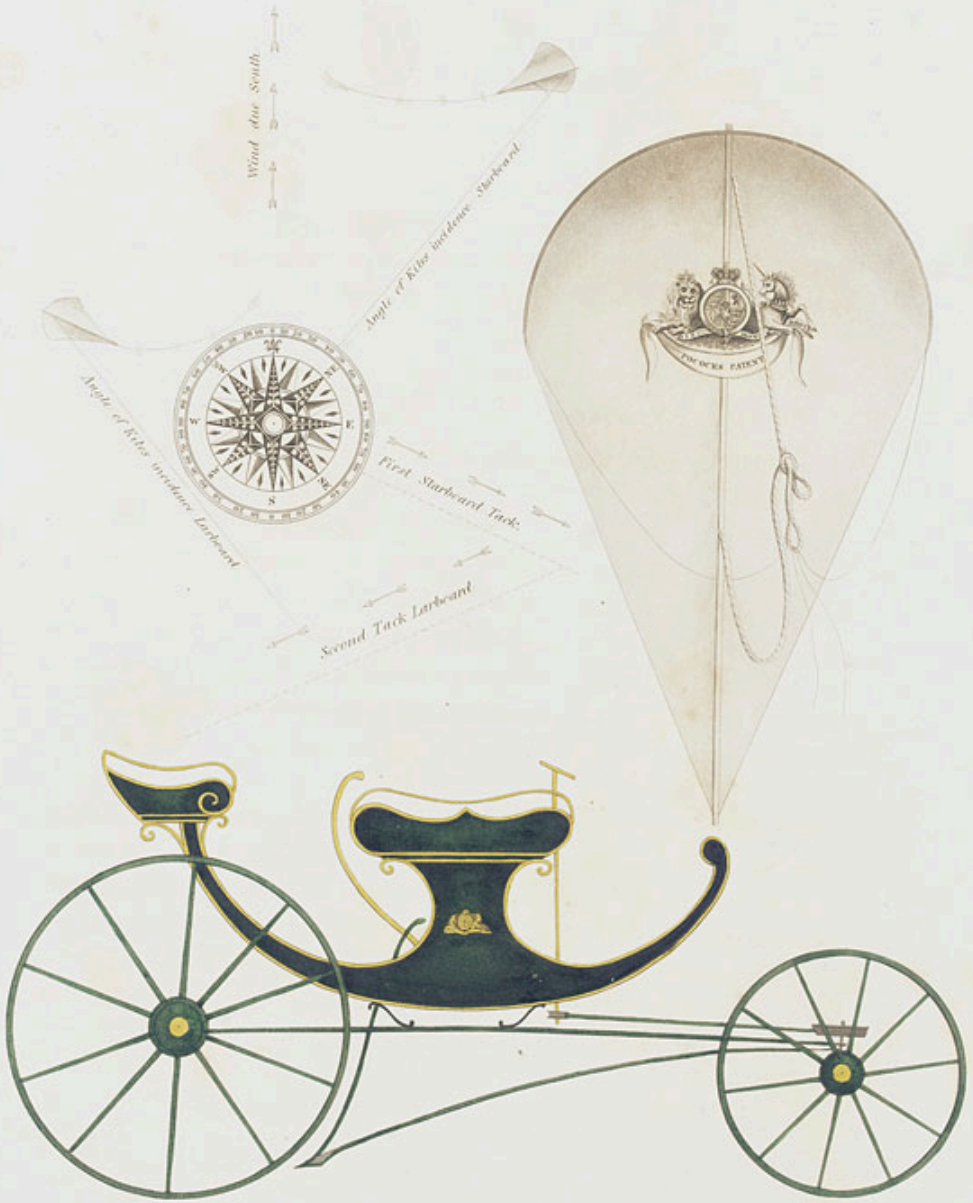
Special Collections: Book of the Month: The Aeropleustic Art or Navigation in the Air by the use of Kites, or Buoyant Sails. University of Glasgow. March 2001.



Pocock’s charvolant



Charvolants travelling in various directions with the same Wind



Patent Kite and Charvolant

Shewing by Mariners Compass the Points of Cars Traverse against the Wind

Further reading

- M. Robinson: Meteorological Kites – Scientific Kites of the Industrial Revolution.
- Peter Lynn: The world’s oldest known kite. Kiteboarding, 3 July 2017.

Golden Age of Kites

Kites at the dawn of aviation, from 1860 until around 1910 (Webster 2003).



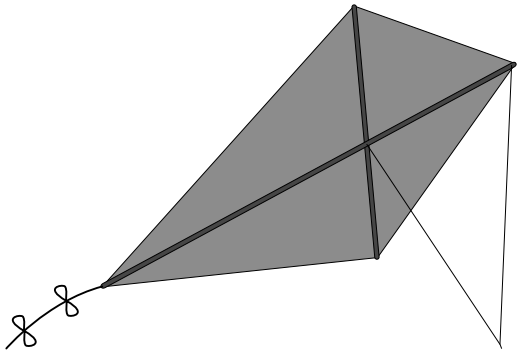
Werner Schmidt/wetterdrachen.de

Technical and scientific applications

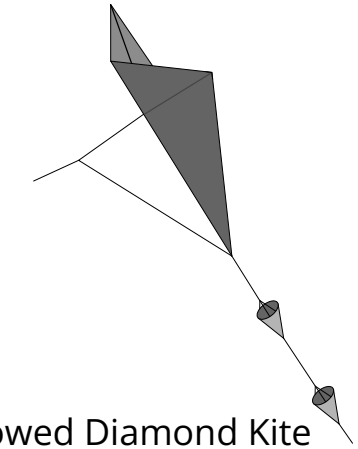
In the second half of the 19th century, kites where used increasingly for technical and scientific applications.

- Kites were used for continued **manned flight** experiments.
- First **aerial photos** were taken from kites in **1882**, just 24 years after first aerial photos from a balloon.
- Kites were an important precursor for **aircraft**, exploring the behavior of the airframe.
- Most importantly was the use for **atmospheric research** and in the beginning of the 20th century, many meteorological stations in Europe and the US employed kite trains (Schmidt and Anderson 2013).
- Main performance criteria where **lift capabilities**, **stability** and **reliability**.

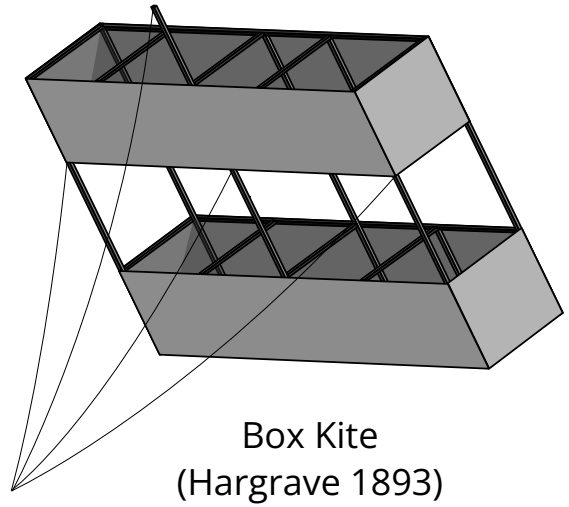
Evolution of kite designs



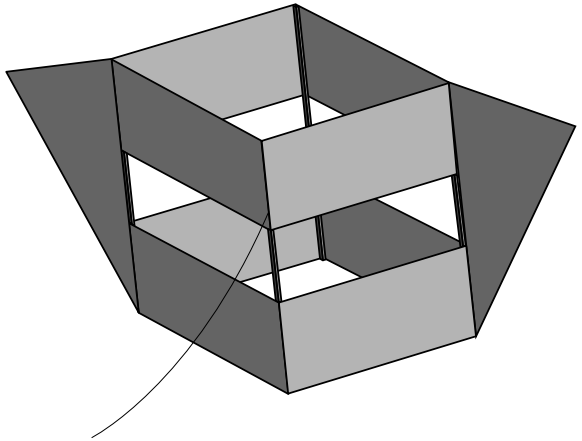
Diamond kite



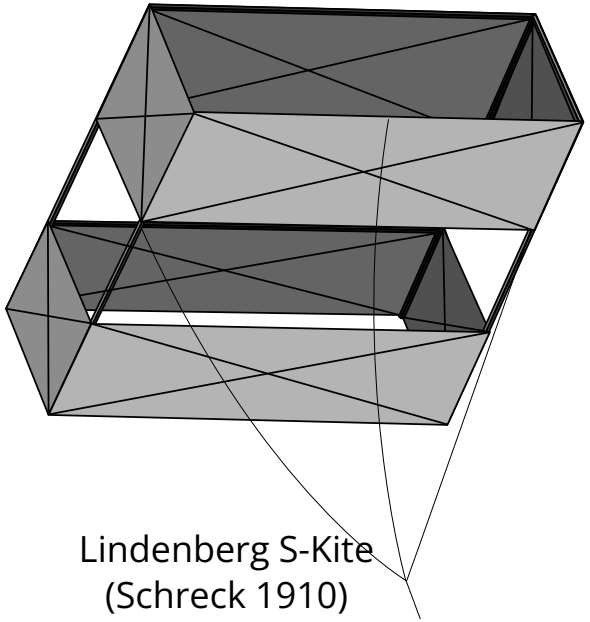
Bowed Diamond Kite
(Eddy 1894)



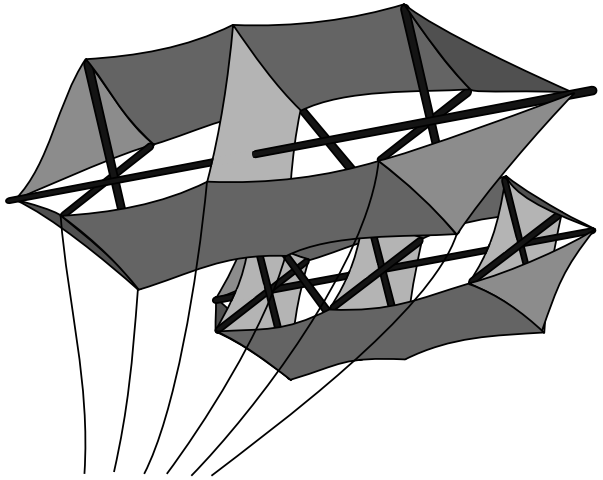
Box Kite
(Hargrave 1893)



Diamond-Cell Kite
(Potter 1894, Köppen 1904)

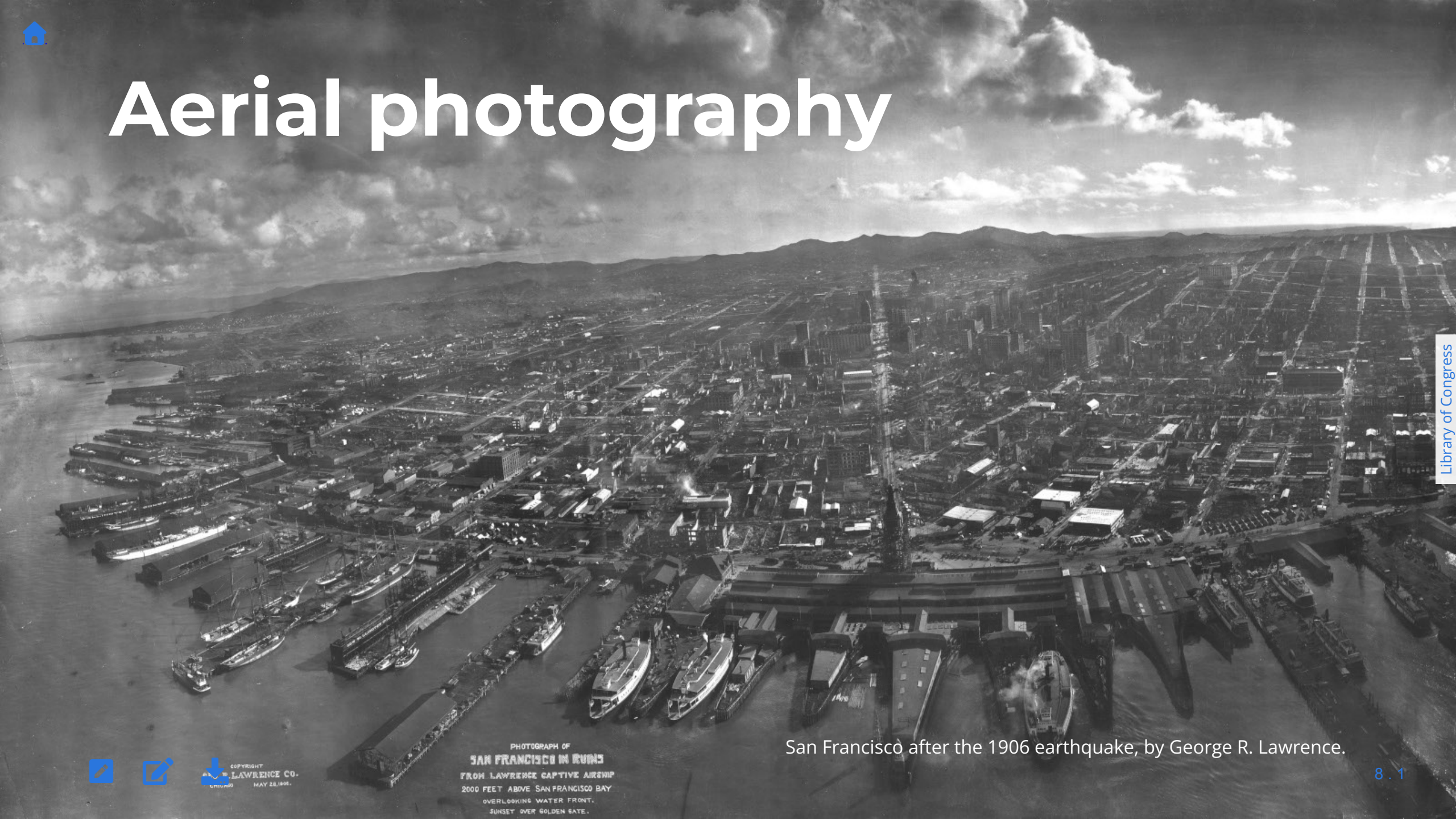


Lindenberg S-Kite
(Schreck 1910)



Lindenberg R-Kite
(Grund 1929)

Aerial photography



San Francisco after the 1906 earthquake, by George R. Lawrence.

Library of Congress

Timeline

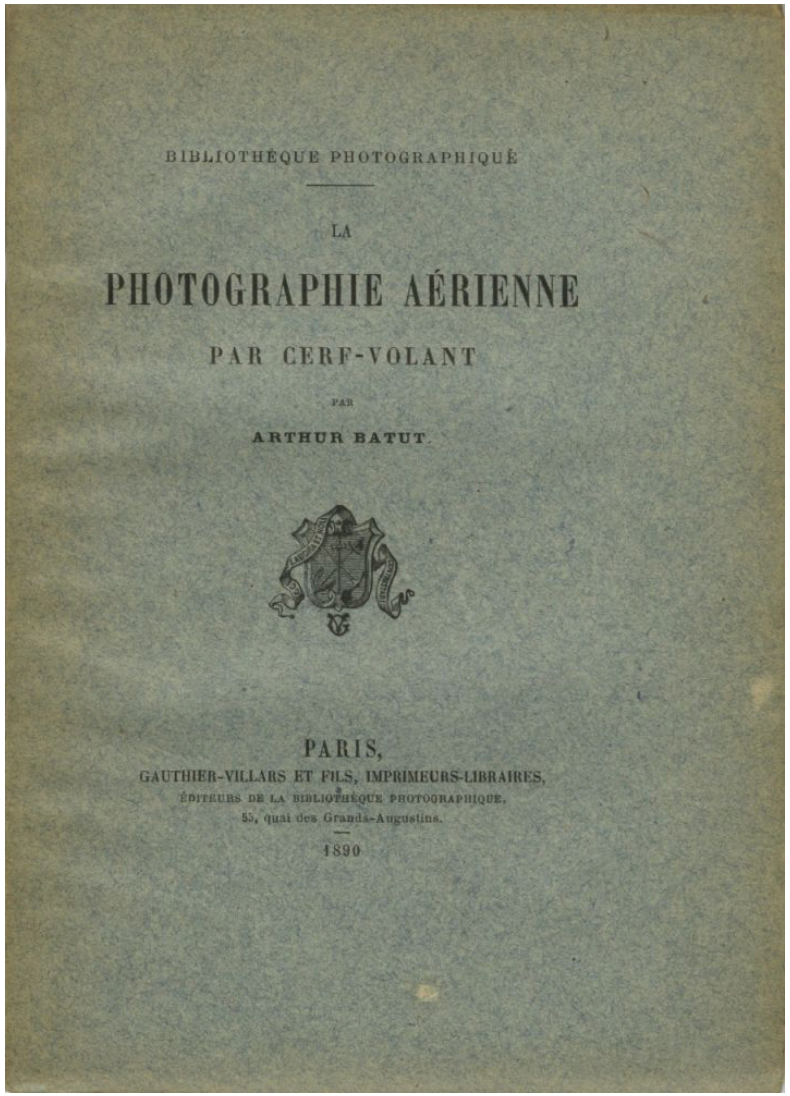
- Kite aerial photography was pioneered by British meteorologist Douglas Archibald in **1887**[1] and French photographer Arthur Batut in **1888**.
- Starting in 1882, Archibald experimented with kites for observations of wind speeds at different altitudes using anemometers attached to the tether.
- For the aerial photo taken in 1887, Archibald used an explosive charge with a timer.
- Aerial photography and manned kite flying weres advanced also by French Marcel Maillot, British Fletcher Baden-Powell, Americans Charles Lamson, William Abner Eddy, George R. Lawrence, Australian Lawrence Hargrave and French Captain Saconney.
- **Flight stability** is the most important requirement for aerial photography kites. Generally, single lined kites are used as they allow very long line lengths and need less intervention from the flyer than steerable designs.

[1] Although disputed in some literature sources because of an apparent lack of photographic proof.

Aerial photography



Batut's camera-kite (1889)



Batut's book (1890)



Arthur Batut (1846-1918)

Photos: Collection l'espace photographique Arthur Batut / Archives départementales du Tarn

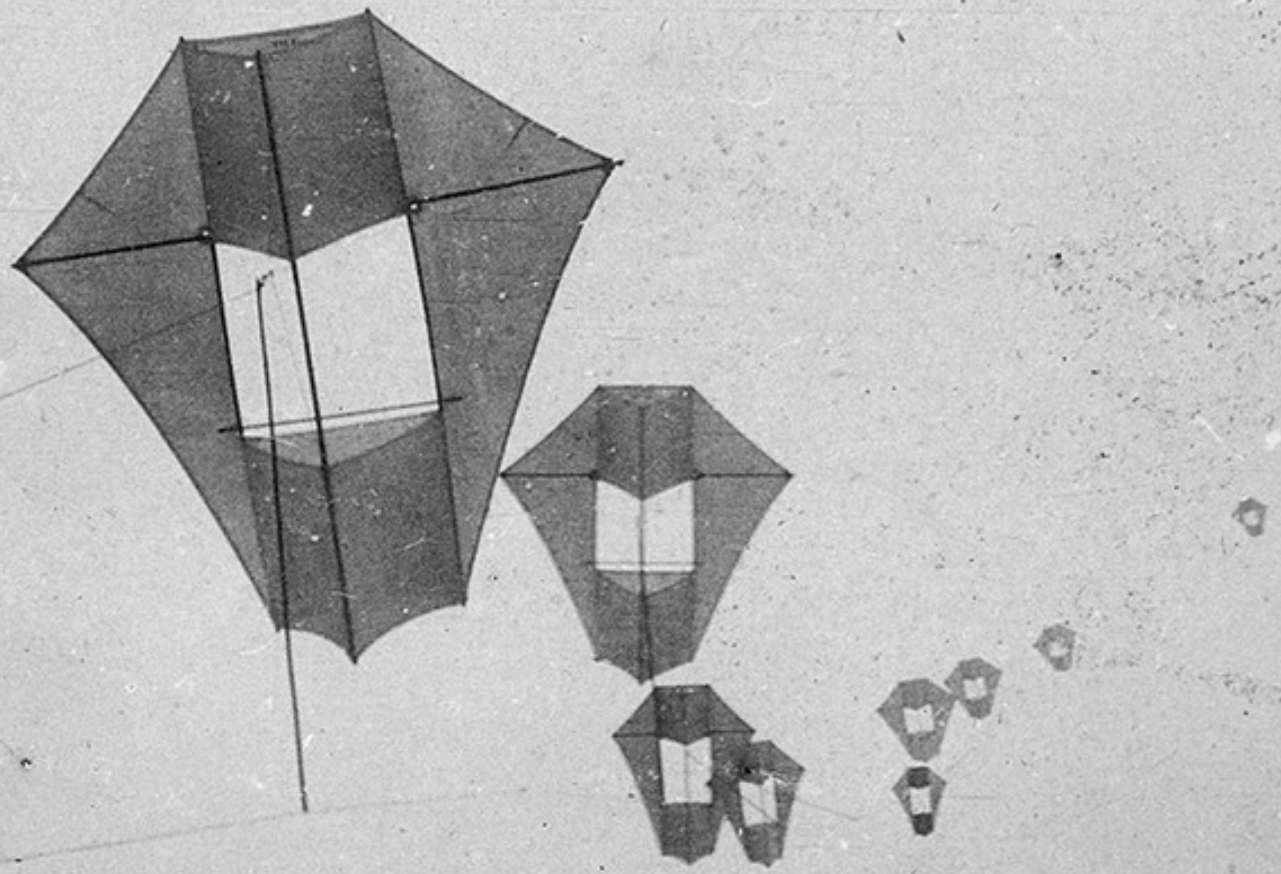


Arthur Batut, The town of Labruguière, southern France (1889).

Collection l'espace photographique Arthur Batut / Archives départementales du Tarn

Lawrence kite train

Kite train (1905).



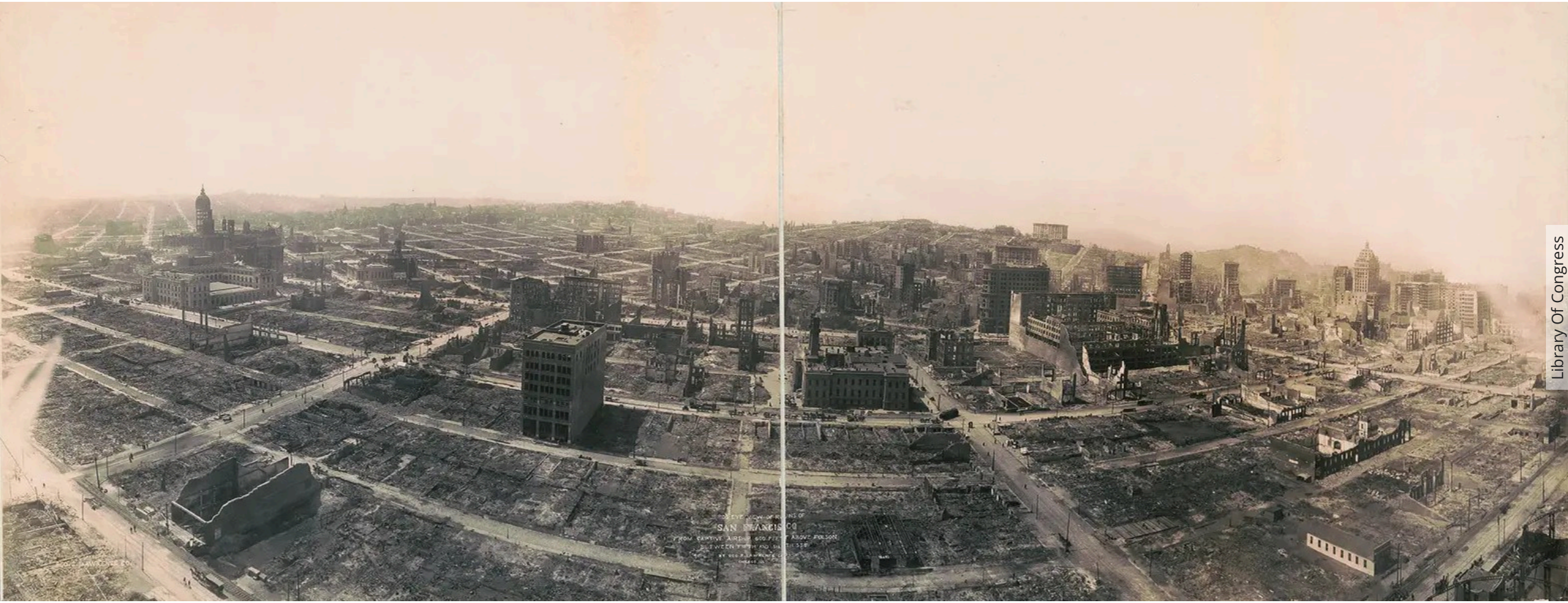
National Archives and Records Administration

Lawrence “Captive Airship”



George Lawrence’s Captive Airship, a kite train and camera-steadying mechanism (1905).

National Archives and Records Administration

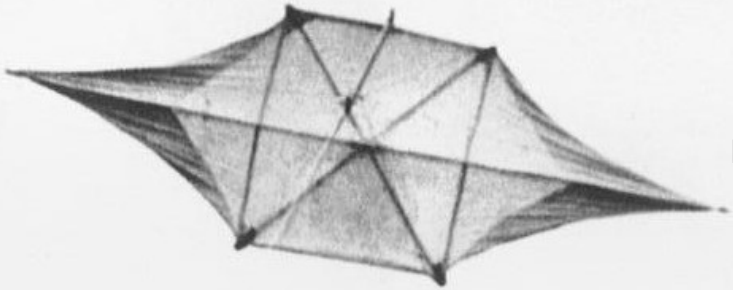


George R. Lawrence: San Francisco in ruins from the kite, 600 meters above San Francisco Bay, overlooking the waterfront (1906).



Library of Congress

Reconnaissance



French soldiers and kite aerial camera.

Smithsonian National Air and Space Museum

Bowed diamond kite (1891)



William Abner Eddy (1850-1909)

- **William A. Eddy** was a journalist from New Jersey who investigated how to lift meteorological and photographic equipment reliably with kites.
- Standard **diamond kites** used a tail for improved **flight stability**, which was problematic for **chaining** several kites to reach higher altitudes.
- Inspired by the bowed kite from Java, the **Malay kite**, which was stable without a tail, he developed the **bowed diamond kite**.
- In **1892**, he was invited to the **Blue Hill Observatory** near Boston (founded 1885) to demonstrate his new lifting technology, which subsequently was adopted.
- The scientific significance of his patented design was short-lived, due to the advent of Lawrence Hargrave's rectangular box kites.
- Nevertheless, in **1910**, a **train of ten Eddy kites** reached an altitude of **7128 m** and set a height record for several years.

Blue Hill Observatory (1897)





Werner Schmidt/wetterdrachen.de

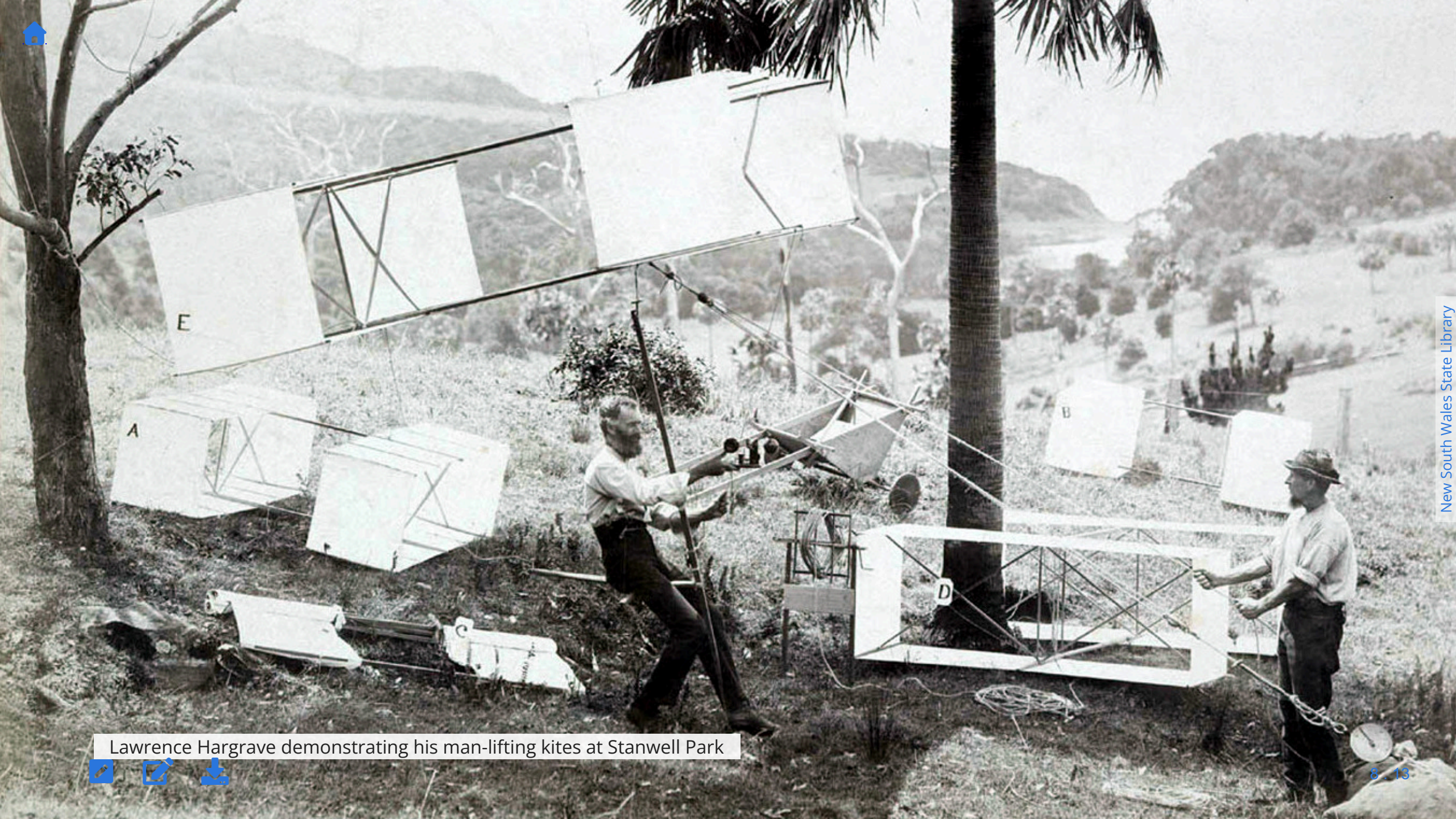
Box kite (1893)



Lawrence Hargrave (1850-1915)

- **Lawrence Hargrave** was a British-born Australian engineer, explorer, astronomer, inventor and aeronautical pioneer.
- Since 1872 he worked at the Sydney Observatory as astronomer.
- Hargrave was a passionate believer in free communication in the scientific community, **refusing to patent** his inventions.
- Following a period of extensive experimentation, he converged on the **box kite** design, which appeared him to be the perfect flying device for **human flight**.
- Hargrave's box kite was illustrated internationally in subsequent years and is considered a **critical link** in the development of the European **airplane**.
- Essentially, the box kite design doubled the wing surface area and by that also the lift, while providing excellent structural stability.
- The cellular structure with vertical wing sections was **inherently stable** which was an important goal for early aeronautical engineers.

Museum of Applied Arts & Sciences



Lawrence Hargrave demonstrating his man-lifting kites at Stanwell Park

New South Wales State Library

Man-lifting kite train (1894)

Power House Museum, Sydney.



Prue Mason/pruemason.wordpress.com

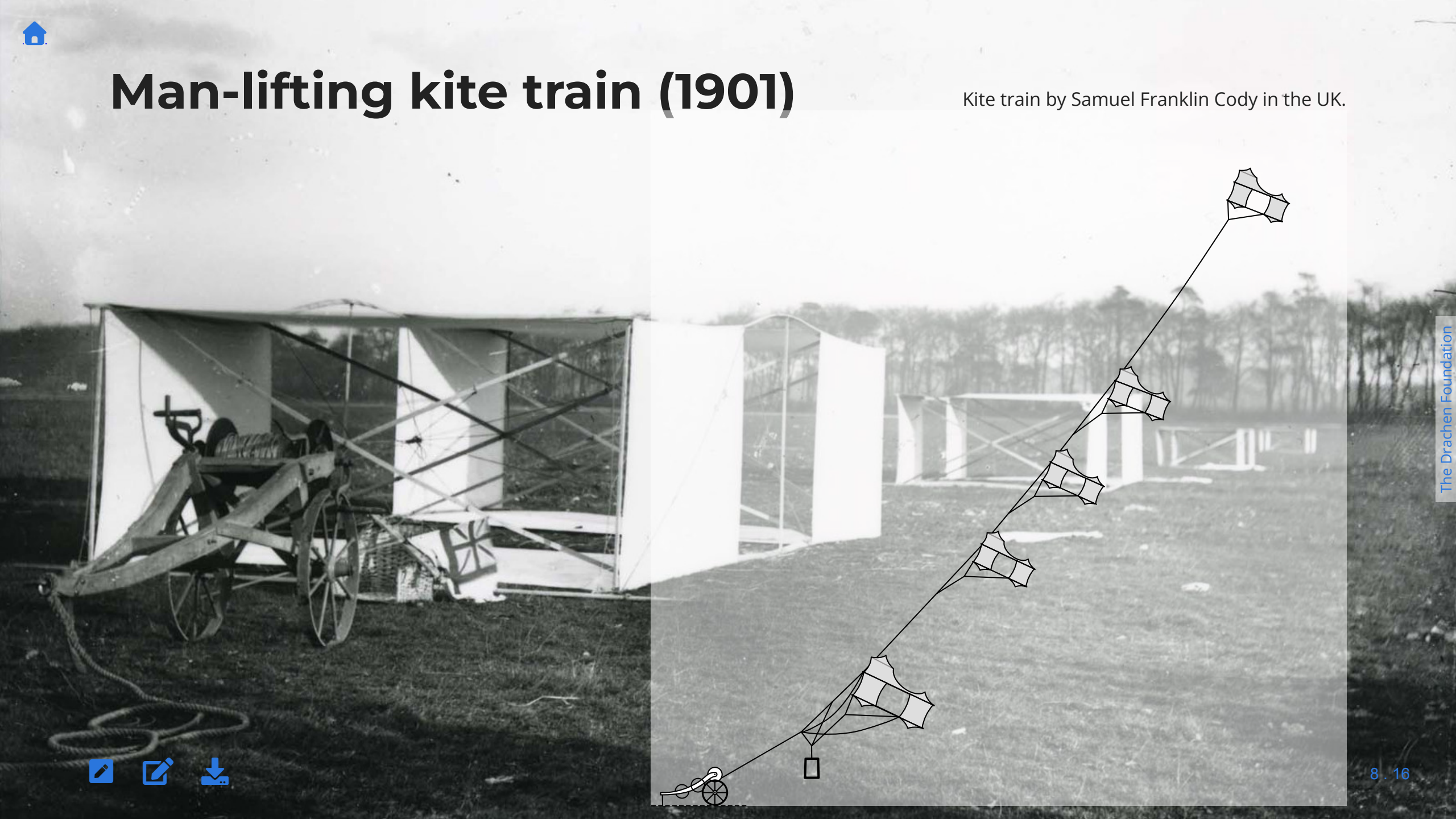


Lawrence Hargrave working on a box kite at Point Piper, Sydney, about 1910

National Museum Australia

Man-lifting kite train (1901)

Kite train by Samuel Franklin Cody in the UK.



The Drachen Foundation

Leslie Jones (1886-1967), Man-kite at Brockton Fair (1930).



Boston Public Library

Cody War Kite (1901)



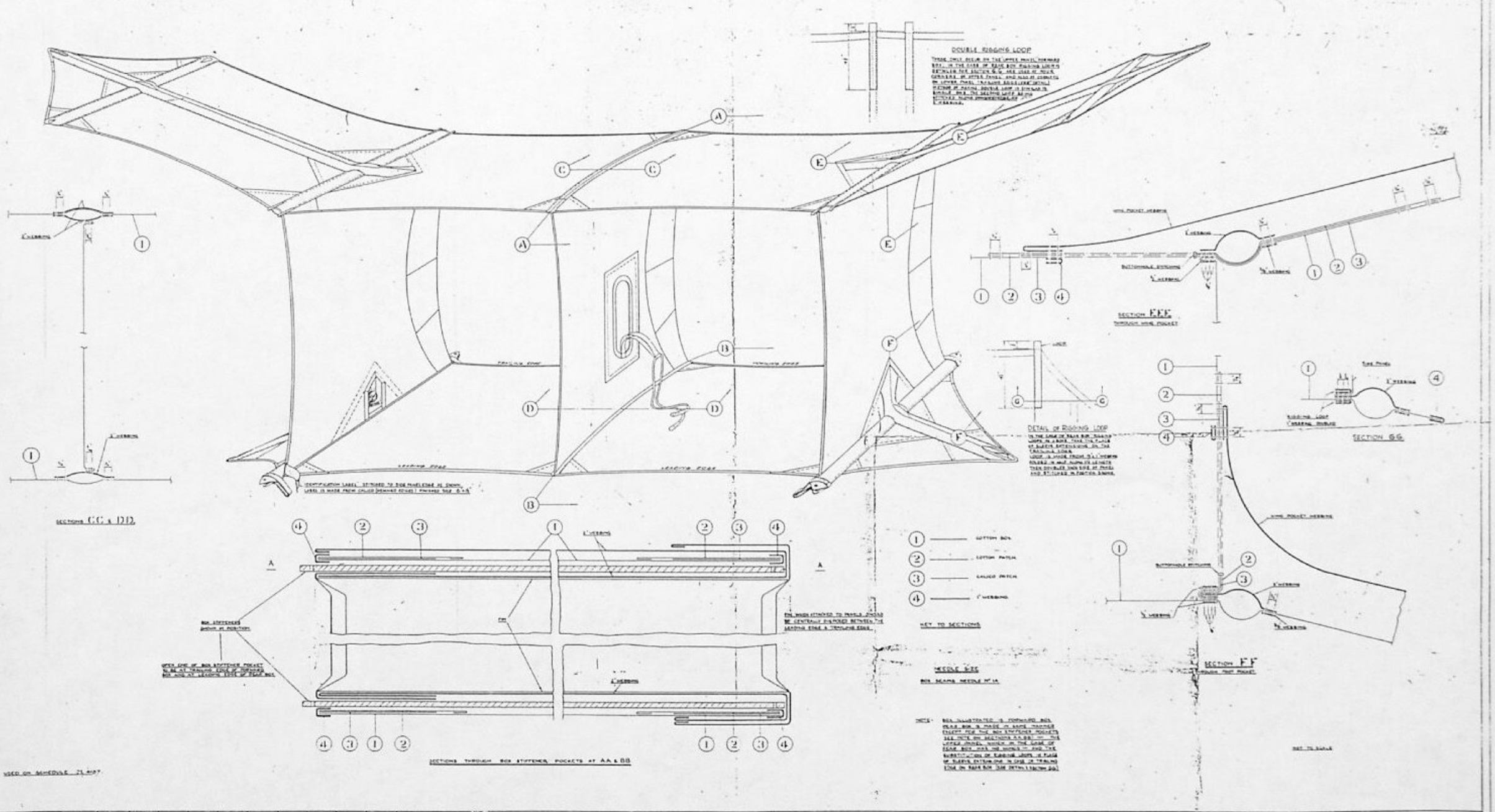
Samuel Franklin Cody (1867-1913)

Wikimedia Commons

- **Samuel Franklin Cody** was a US Wild West showman and early pioneer of manned flight.
- He was also the first man to fly an aeroplane built in Britain, on 16 October 1908.
- He is most famous for his work on the large kites known as Cody War-Kites, that were used by the British before World War I as a **smaller alternative to balloons** for artillery spotting.
- He combined Hargrave's box kites with flexible winglets as a passive depower mechanism and for flight stability.
- In 1908, the War Office officially adopted Cody's kites for the Balloon Companies he had been training.
- He later moved to powered aviation, and died on 7 August 1913 when his latest design, the Cody Floatplane, crashed near Farnborough.



Cody war kite Mark III.



ISSUE No. ALTERATION No.

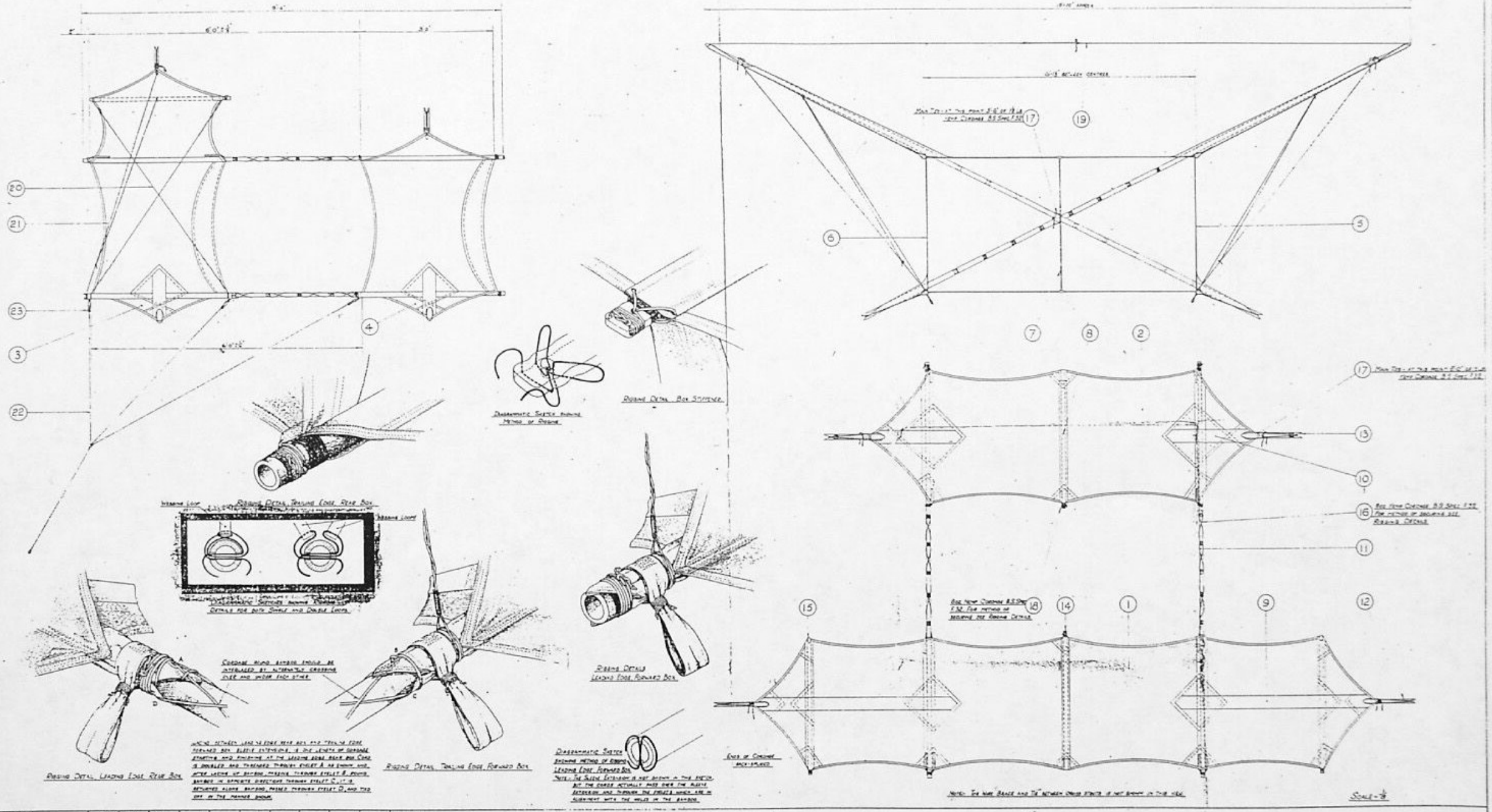
TITLE:- BOX, KITE, CODY, 3FT, MARK III.

ISSUED BY DRAWING OFFICE DIRECTORATE OF SCIENTIFIC RESEARCH & TECHNICAL DEVELOPMENT AIR MINISTRY.

DRAWN	TRACED	CHECKED	DATE	APPROVED	DATE

DRG No 02/4108

8 . 20



ISSUE Nº B
ALTERATION E.D.S.

TITLE:- KITE, CODY, 3 FT Mk III - G.A.

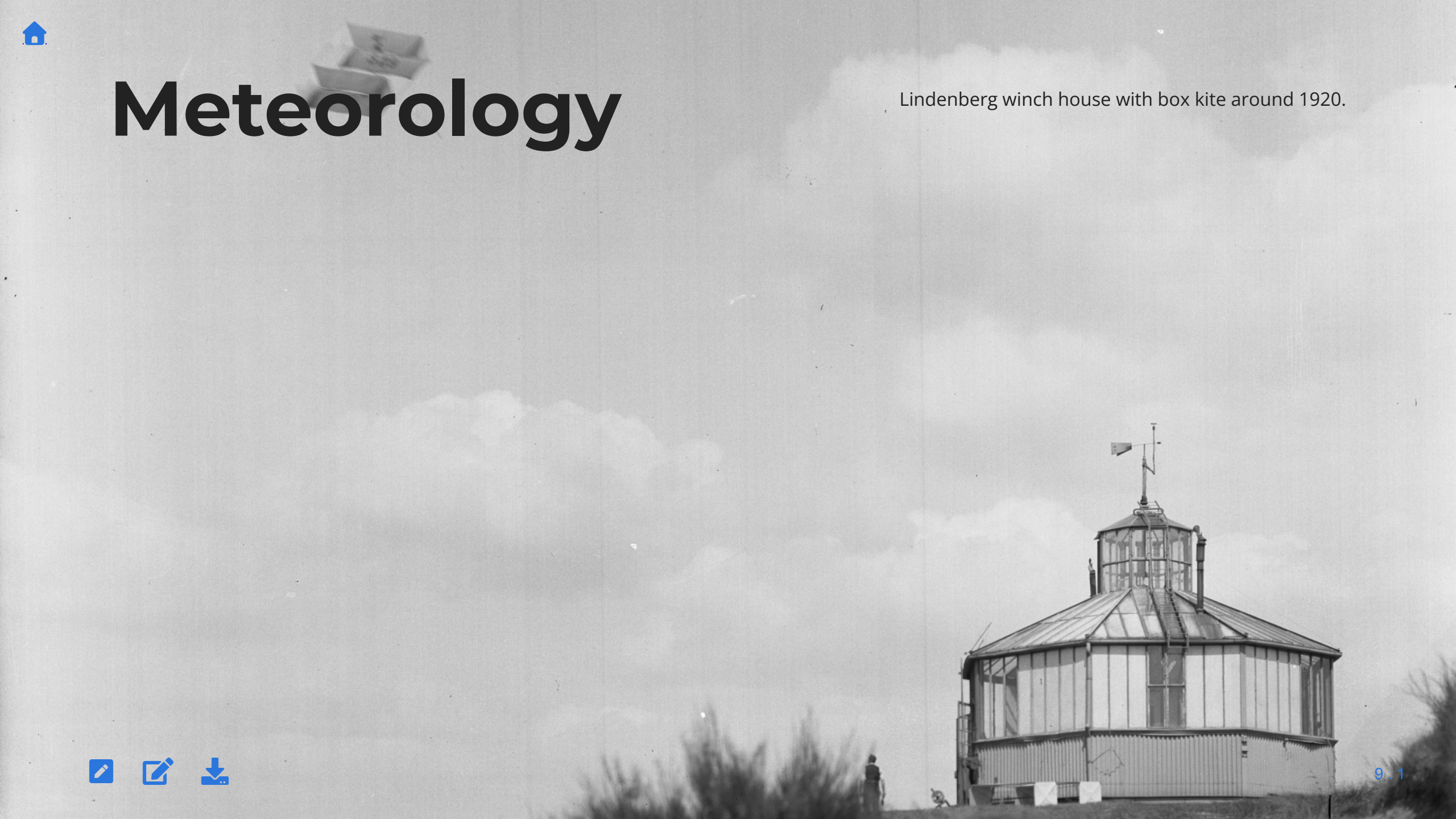
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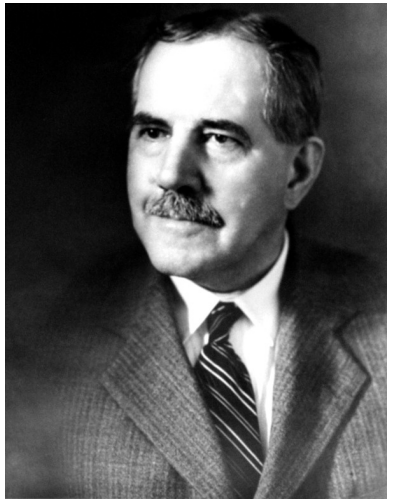
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Meteorology



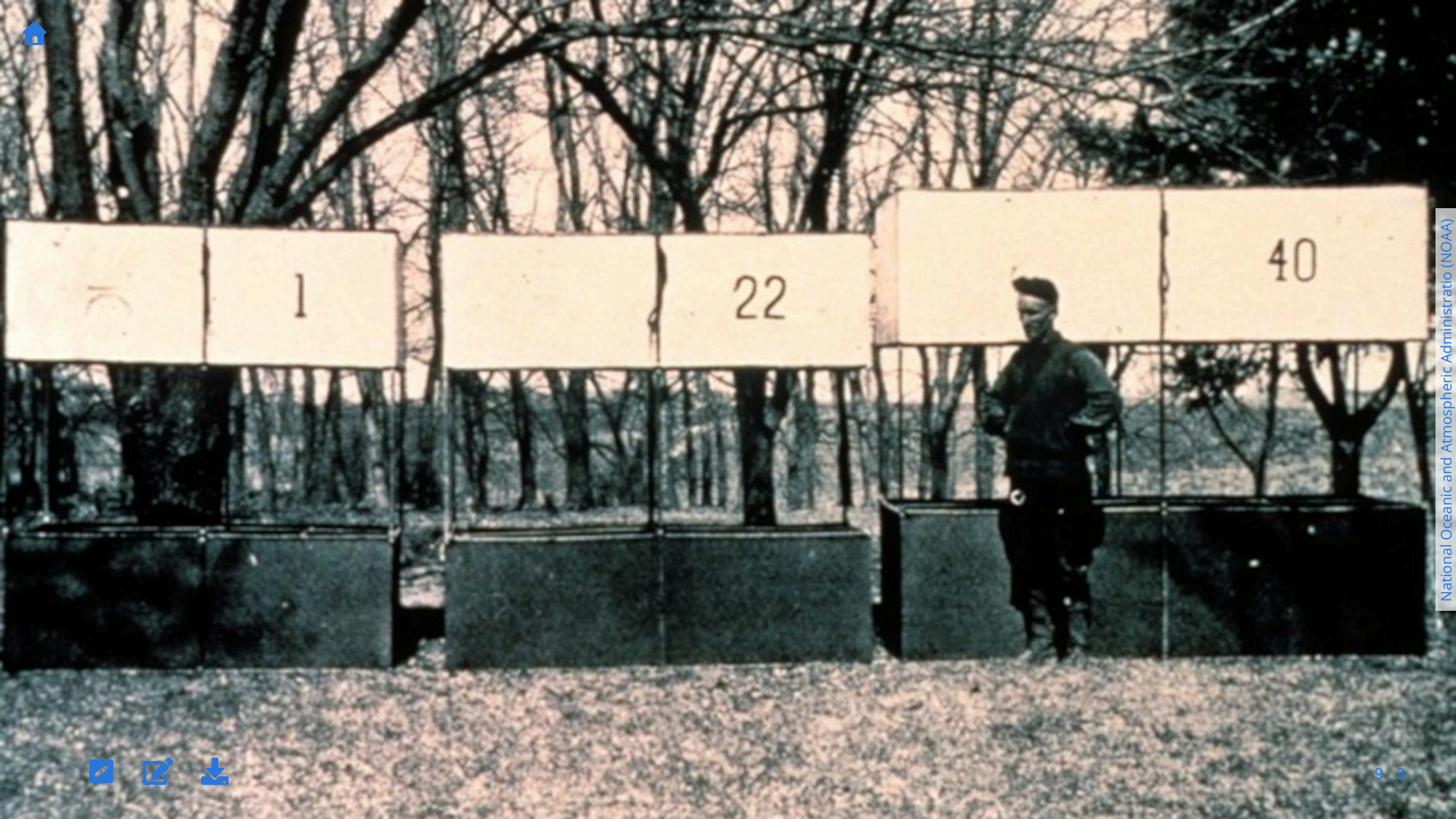
Lindenberg winch house with box kite around 1920.

Marvin Kite (1897)



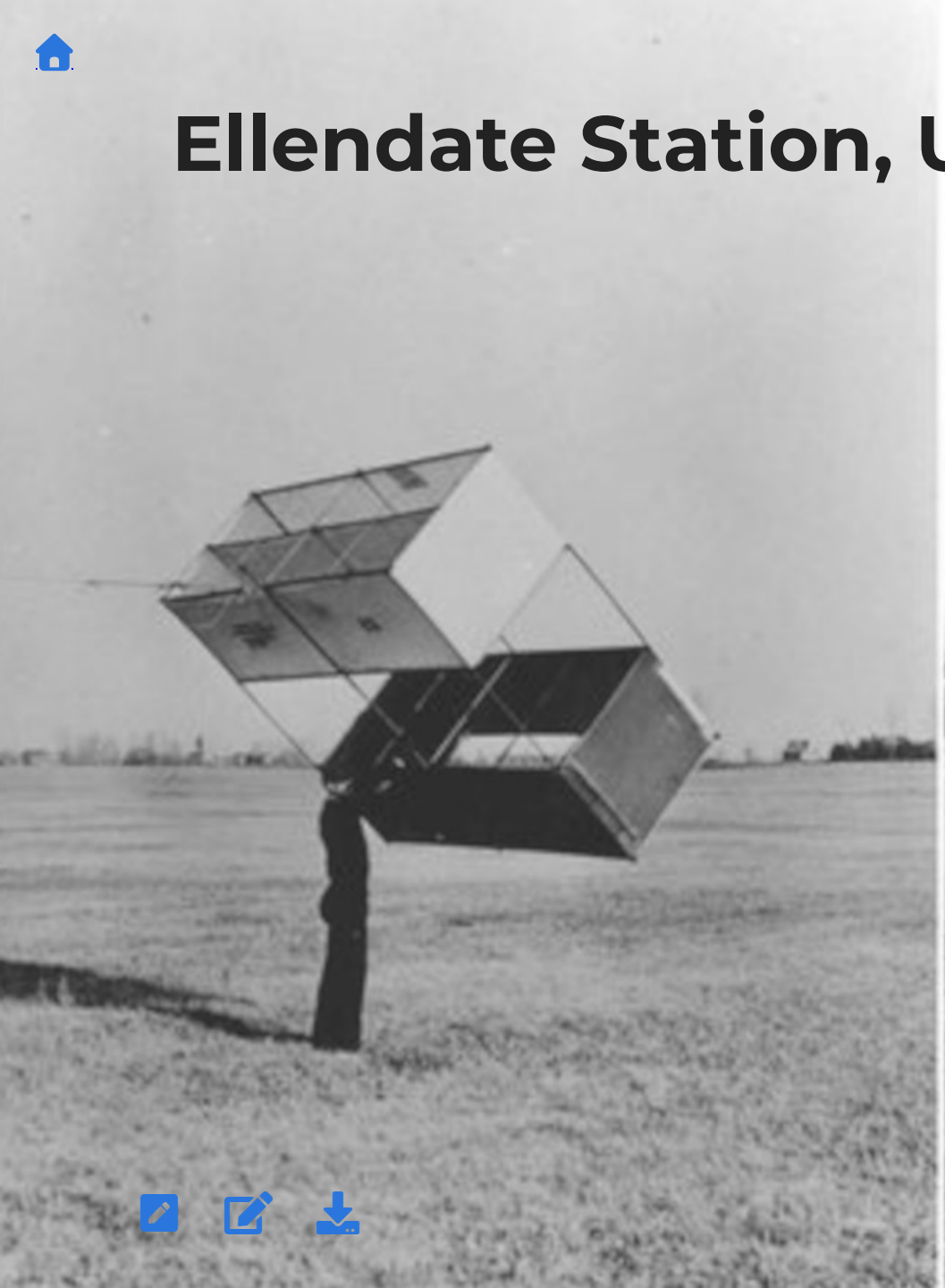
Charles F. Marvin (1858-1943)

- **Charles Frederick Marvin** was an American meteorologist.
- In 1883, he was appointed to the United States Army Signal Corps of the United States Army.
- In **1891**, he was transferred to the newly created civilian **Weather Bureau**, where he became professor of meteorology in **1903**.
- In **1896** he won a competition with his article The Mechanics and Equilibrium of Kites, published one year later in Monthly Weather Review.
- From **1897** on his radical redesign of the Hargrave box kite was used at **17 US weather stations**.
- While Hargrave's box kite allowed a degree of twisting along the span, Marvin's redesign used an entirely **rigid box frame**.
- The kite was built in tree sizes, a standard version, a smaller one for strong wind, and a larger one for light wind.



National Oceanic and Atmospheric Administratio (NOAA)

Ellendate Station, US Weather Bureau





National Oceanic and Atmospheric Administratio (NOAA)

Diamond kite (1904)

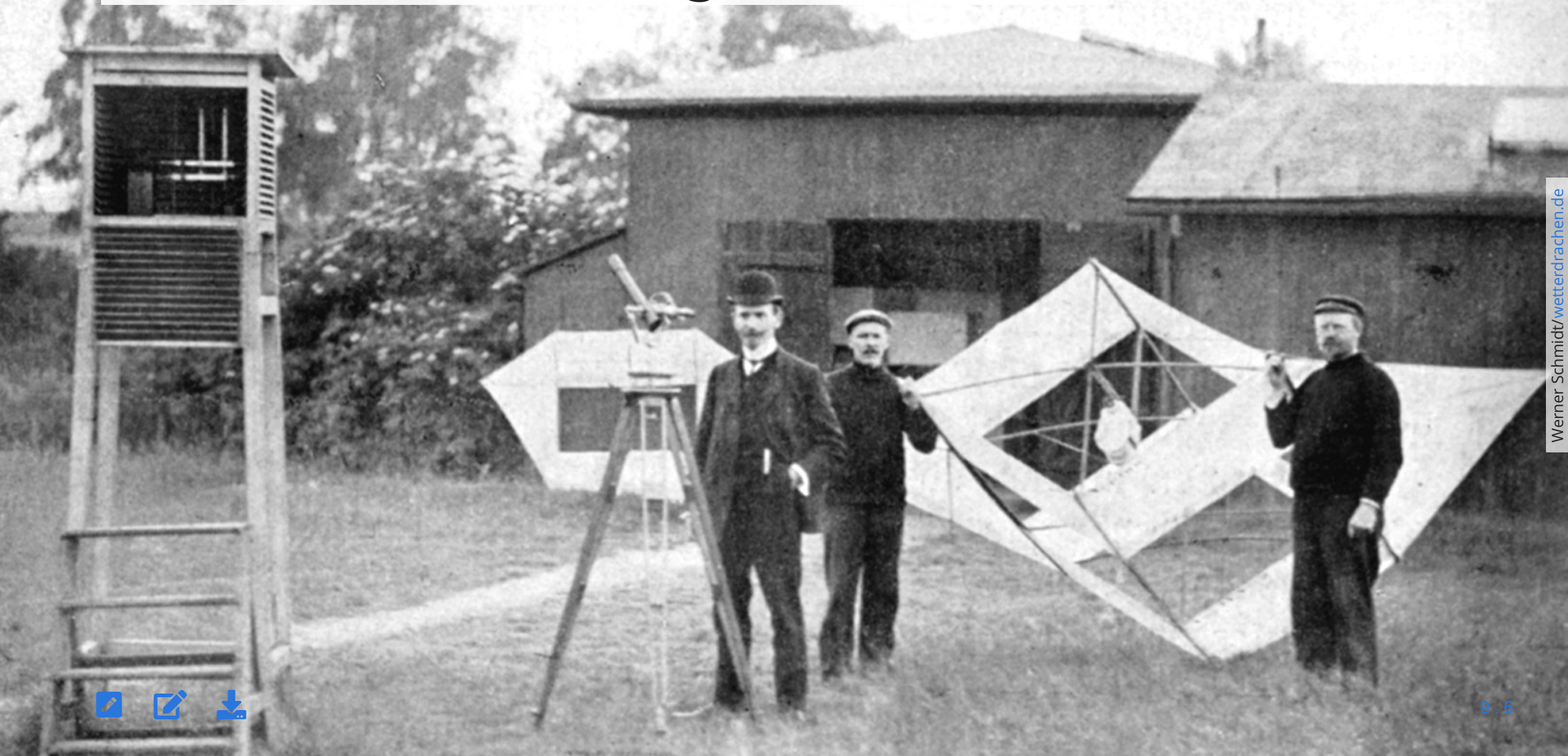


Wladimir Köppen (1846-1940)

- **Wladimir Köppen** was a Russian-German geographer, meteorologist, climatologist and botanist.
- In 1875, he was appointed as head of the new Division of Marine Meteorology at the German naval observatory in Hamburg.
- He is considered to be the principal **founder of climatology and meteorology**.
- To improve his weather predictions, Köppen started using kites in **1898**, first building several Malay kites and a Hargrave box kite.
- In 1903 he established a larger **kite station** in Groß Borstel, a village outside of **Hamburg**.
- The facility included a rotatable wooden house, with an engine-powered winch.
- The kites were flown to about **2 to 4 km altitude**, measuring air pressure, temperature, humidity, wind speed and direction.
- In **1904** Köppen constructed a box kite with rhomboidal cross section and winglets, which he name **diamond kite**.

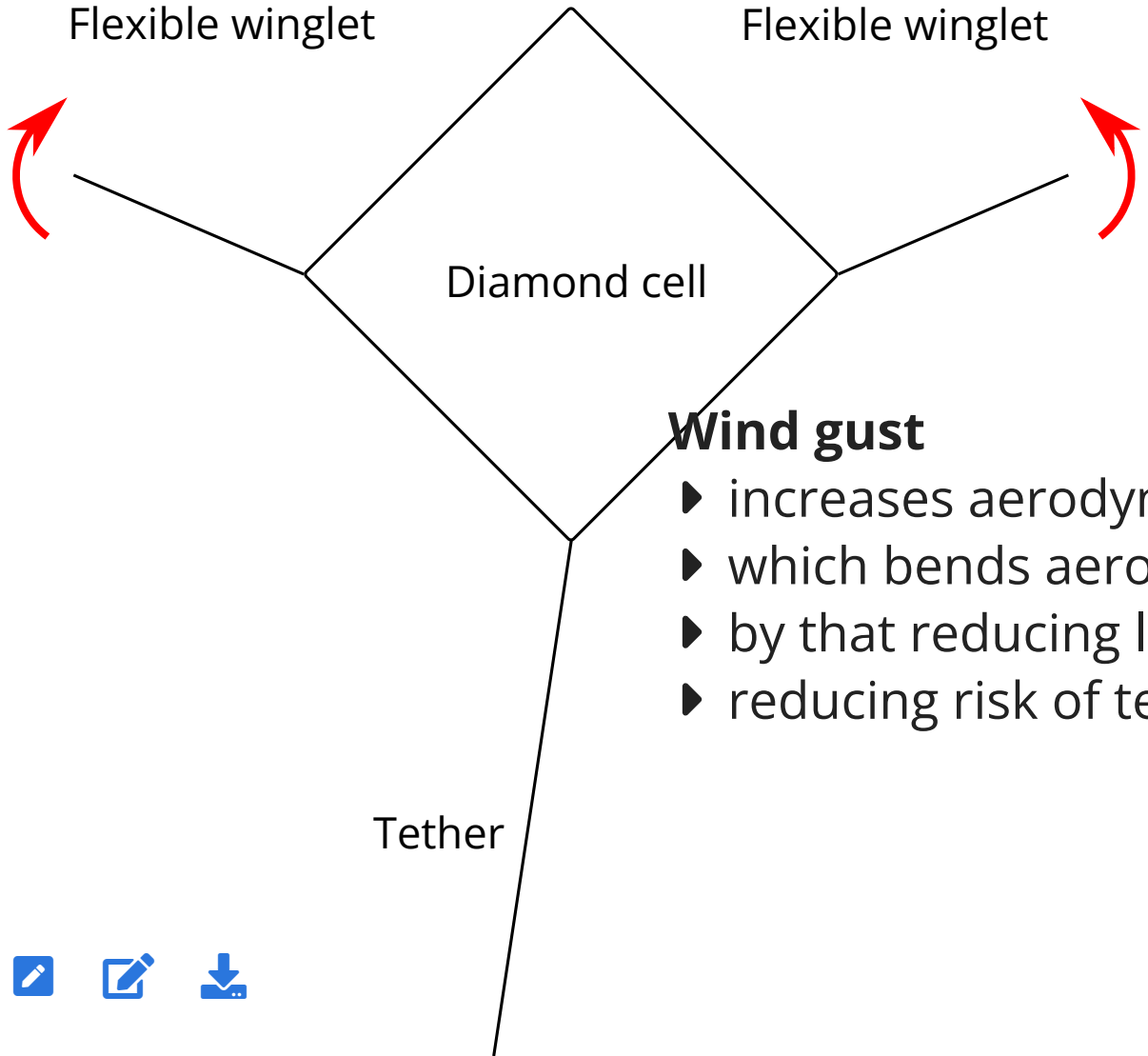
University of Graz Library

Kite station Hamburg-Groß Borstel



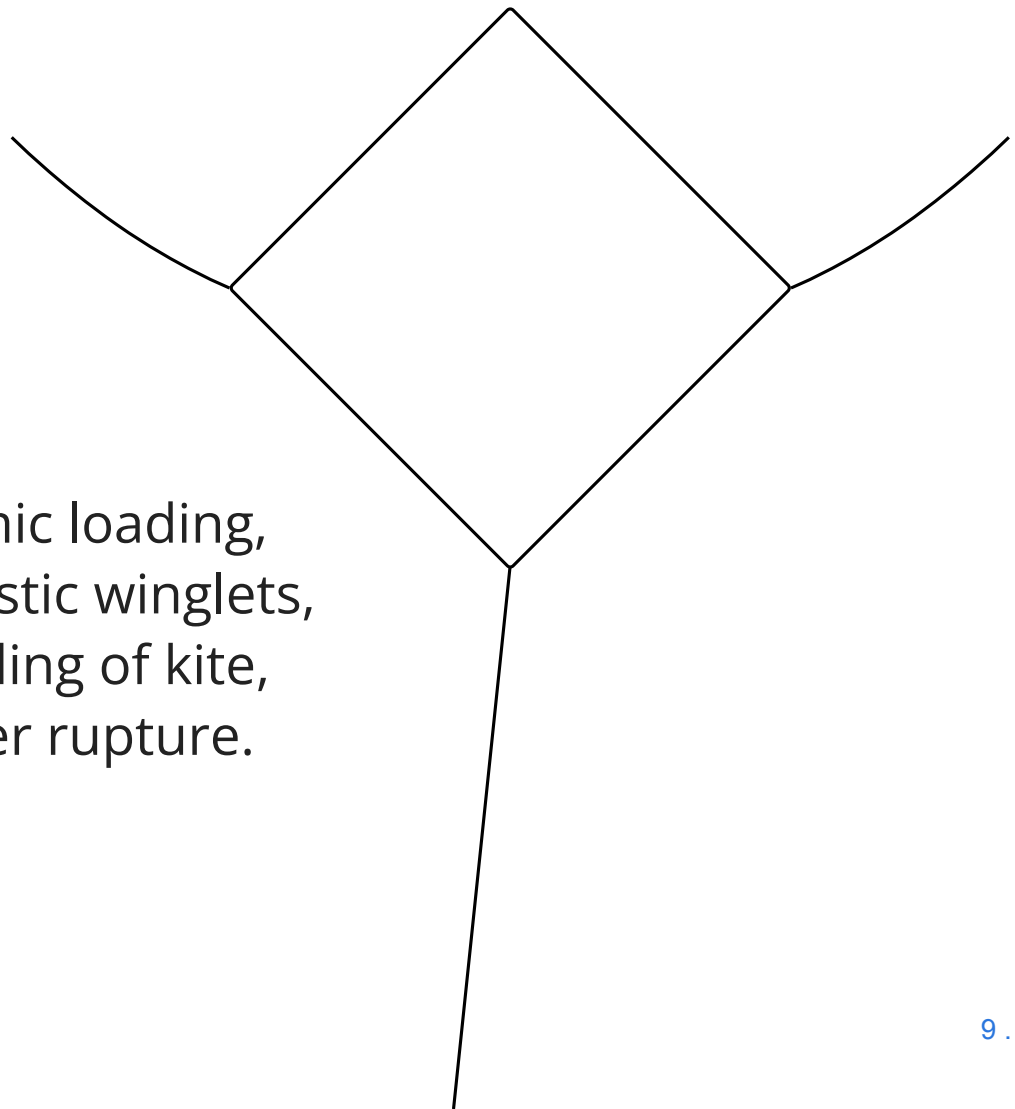
Werner Schmidt/wetterdrachen.de

Passive aeroelastic deformation mechanism

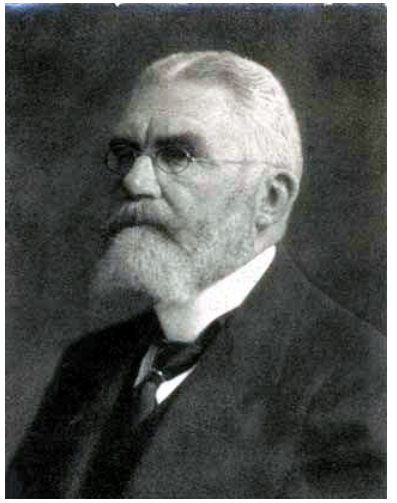


Wind gust

- increases aerodynamic loading,
- which bends aeroelastic winglets,
- by that reducing loading of kite,
- reducing risk of tether rupture.



Lindenberg N-Kite (1900-1905)



Richard Assmann (1845-1918)

- **Richard Assmann** was a German meteorologist and physician.
- He is considered a co-founder of **atmospheric science**, the study of the Earth's atmosphere and its various inner-working physical processes.
- In **1900** he founded the Aeronautical Observatory in Berlin-Tegel, and from **1905** until 1914 was a first director of the Aeronautical Observatory Lindenberg.
- The **Lindenberg N-Kite** (**N**ormaldrachen) is the result of a longer series of tests, which was already started at the Aeronautical Observatory in Berlin-Tegel.
- Starting point for the scientists was the Marvin Kite, which was used by the US Weather Bureau.
- One point of improvement was the simplification of the box frame.
- The kite was built in three sizes, with 4, 6, and 7 horizontal wing surface area.

Leibniz-Institut für Länderkunde e. V.



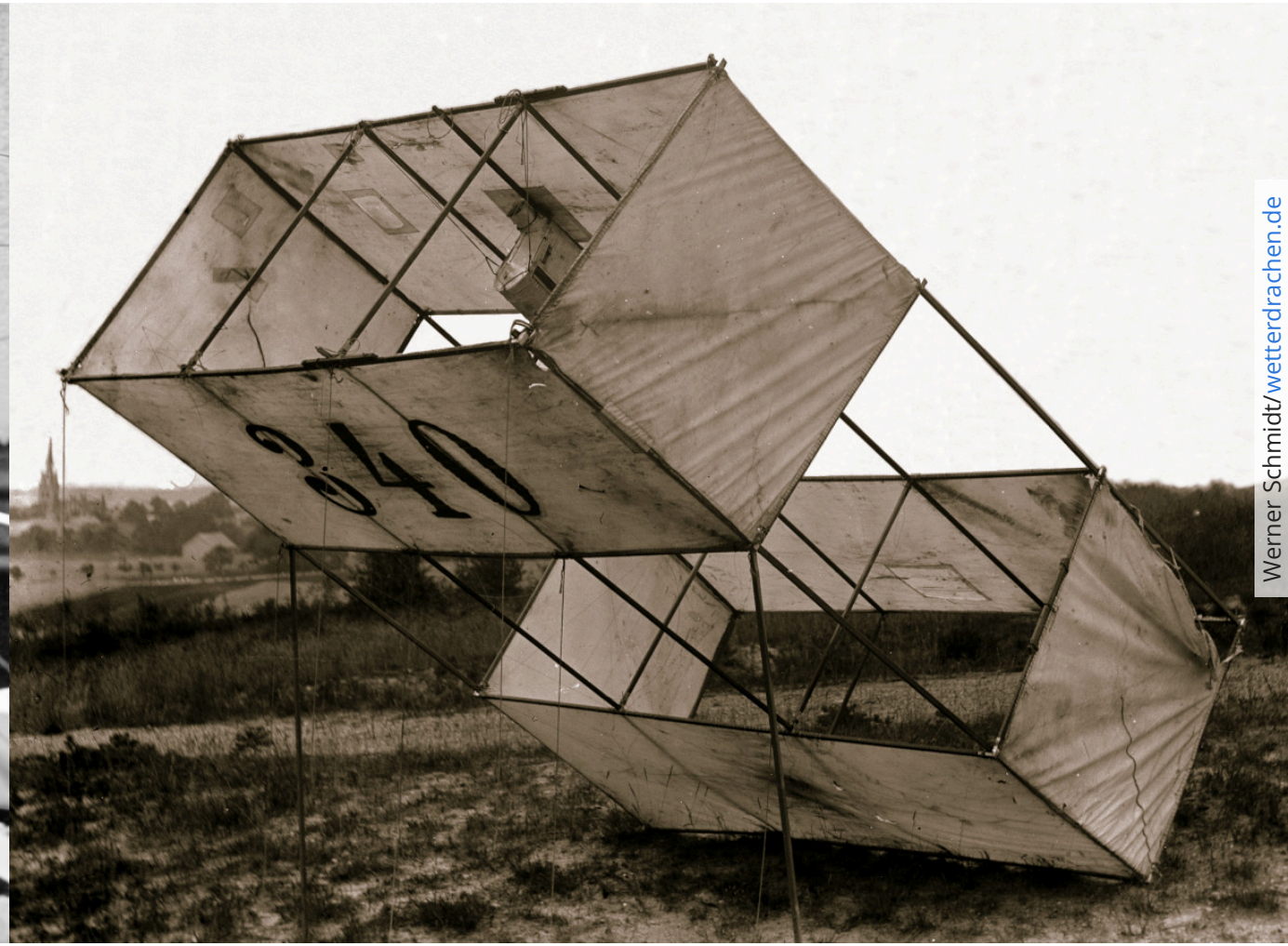
Lindenberg winch house around 1905.

Ullstein bild Dtl.

Lindenberg N-Kite (Normaldrachen)



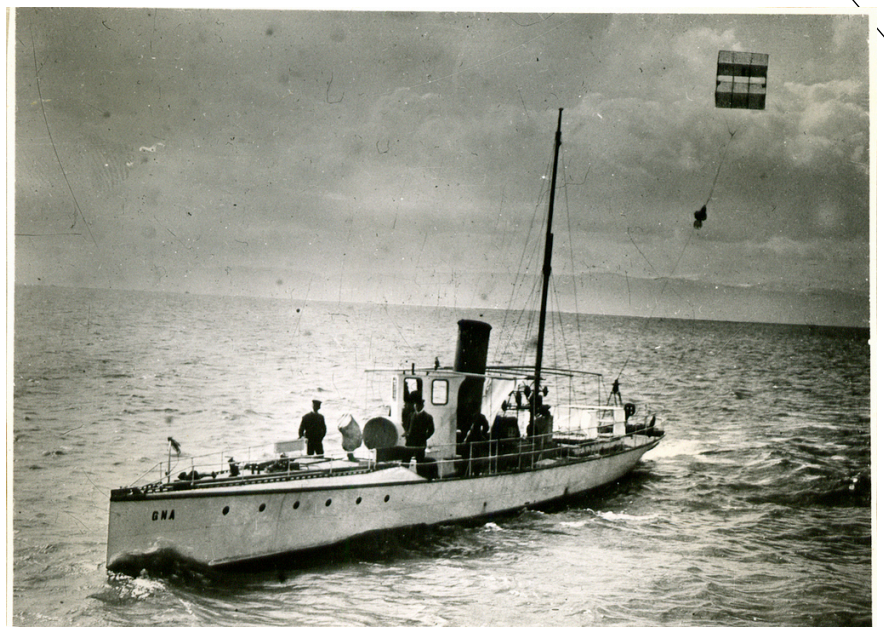
Barograph



Werner Schmidt/wetterdrachen.de

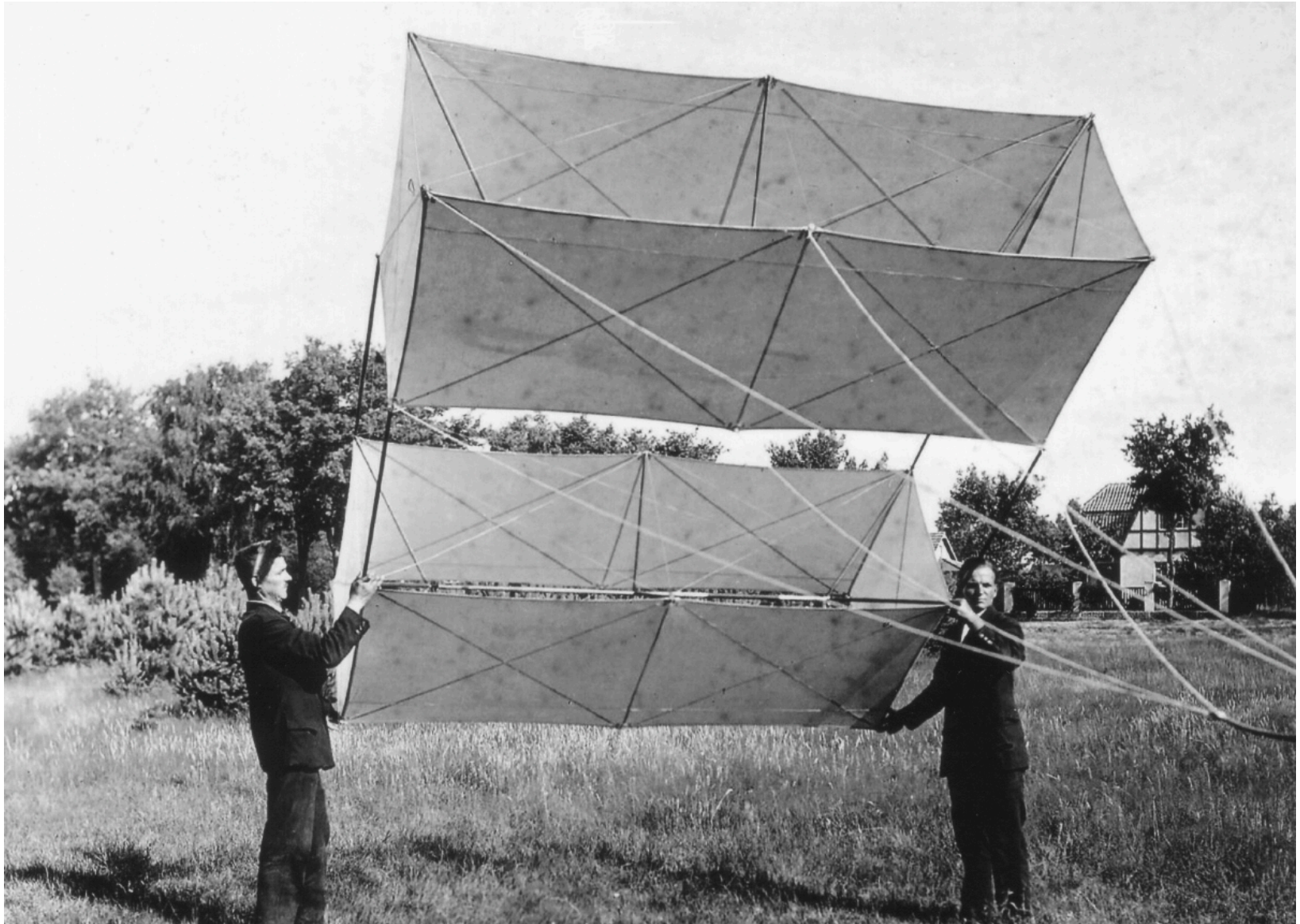
Research ship Gna (1907-1954)

for atmospheric resarch on lake Constance



BSH Digital Library

Lindenberg S-Kite (Schirmdrachen)



Werner Schmidt/wetterdrachen.de

Lindenberg S-Kite



Lindenberg Weather Museum

Lindenberg S-Kite



Lindenberg Weather Museum

Lindenberg R-Kite (Regulierdrachen)

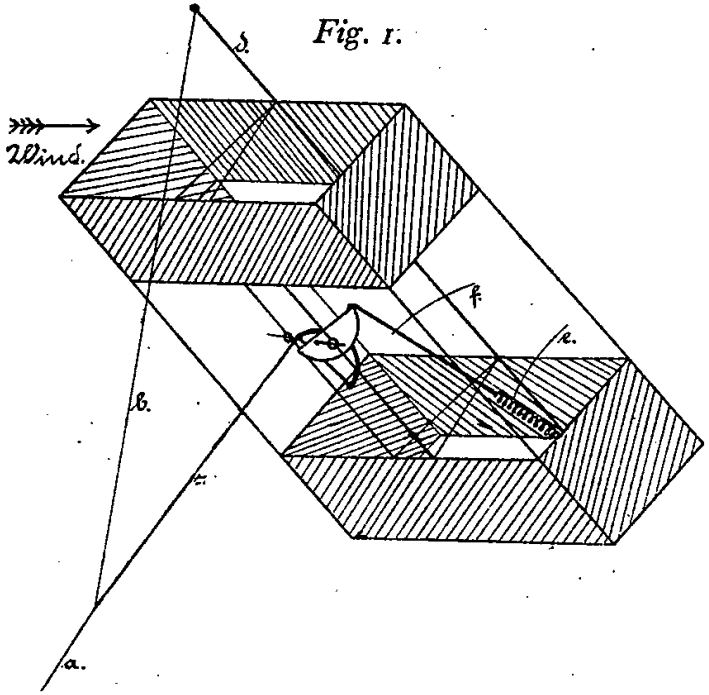


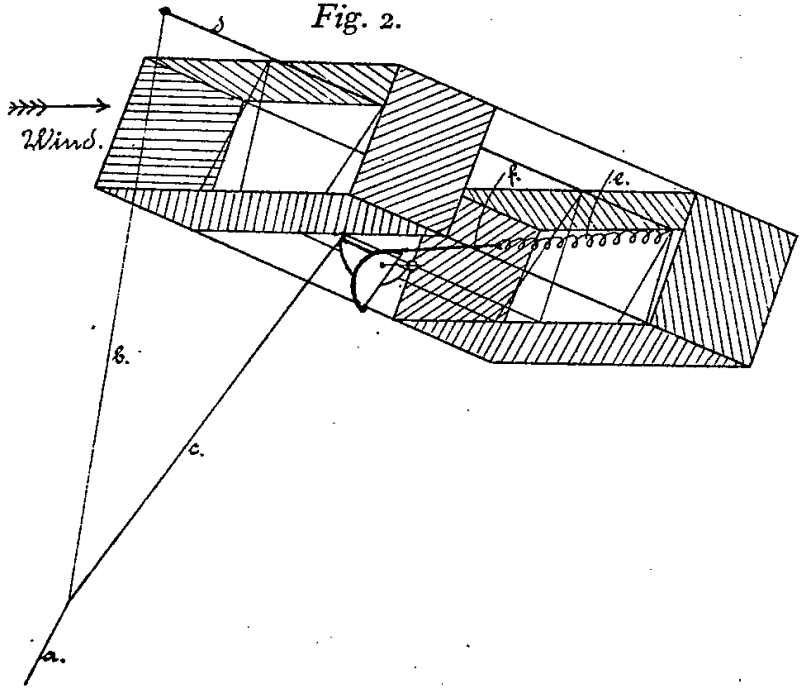
Rudolf Grund (1886-1965)

- **Rudolf Grund** was hired in 1907 as an apprentice by the Lindenberg Observatory, participating in measurement campaigns with balloons and kites and eventually became head of flight operation.
- He is regarded the most important German **kite designer** for meteorological research.
- He knew the shortcomings of N- and S-Kites and in **1916** patented a **passive depower** mechanism for box kites.
- His subsequent redesign, the “Regulierdrachen”, was flown for the first time in **1929**.
- The adaptive kite combined the successful inner skeleton of the S-Kite with two innovations: a hinged connection of front and rear cells with an elastic member.

Werner Schmidt/wetterdrachen.de

Passive pitch mechanism (Grund patent 1916)





Low wind speed

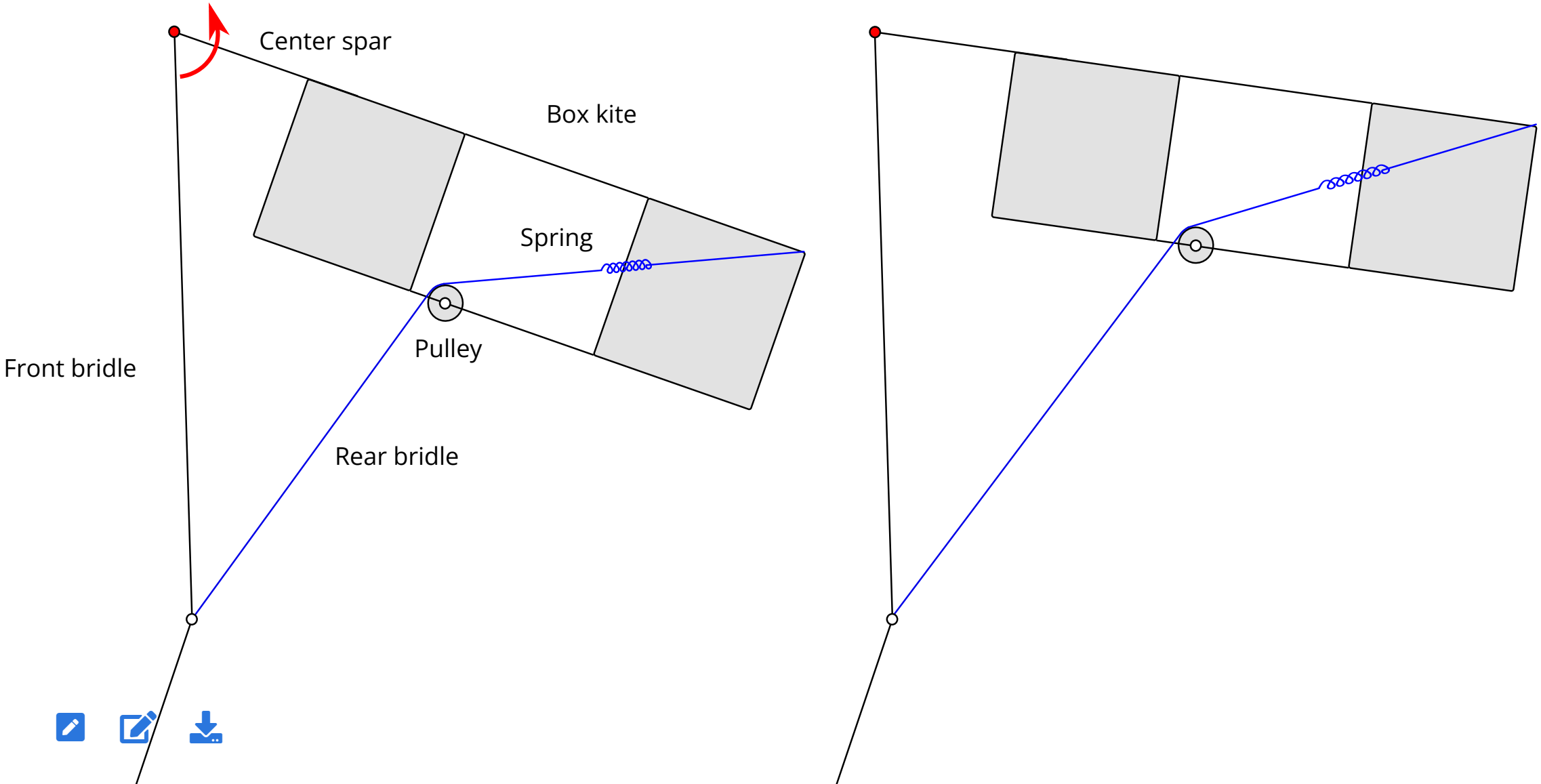
- High angle of attack
- Traction force maximized

High wind speed

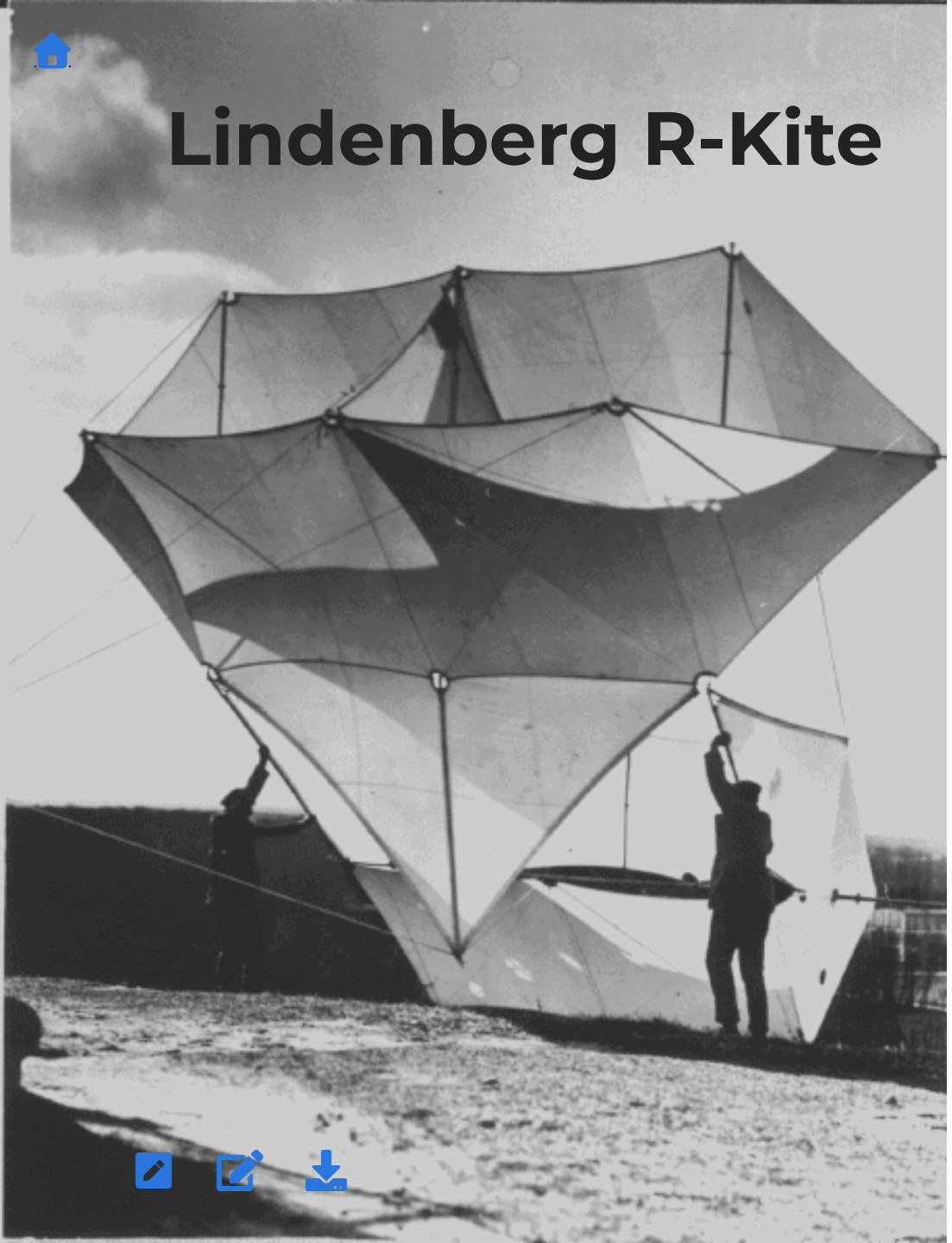
- Low angle of attack
- Traction force limited

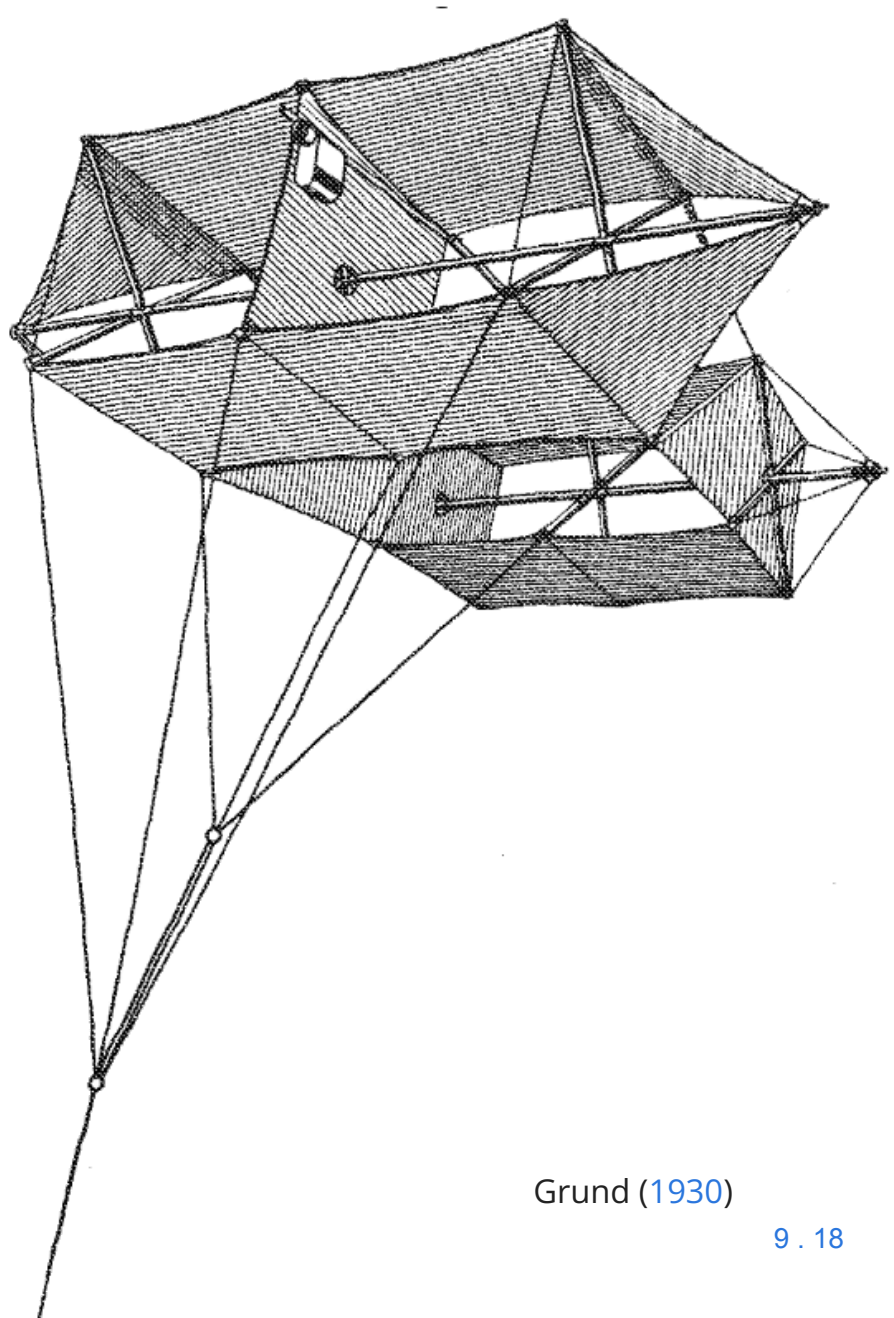
Grund (1916)

Passive pitch mechanism (Grund patent 1916)



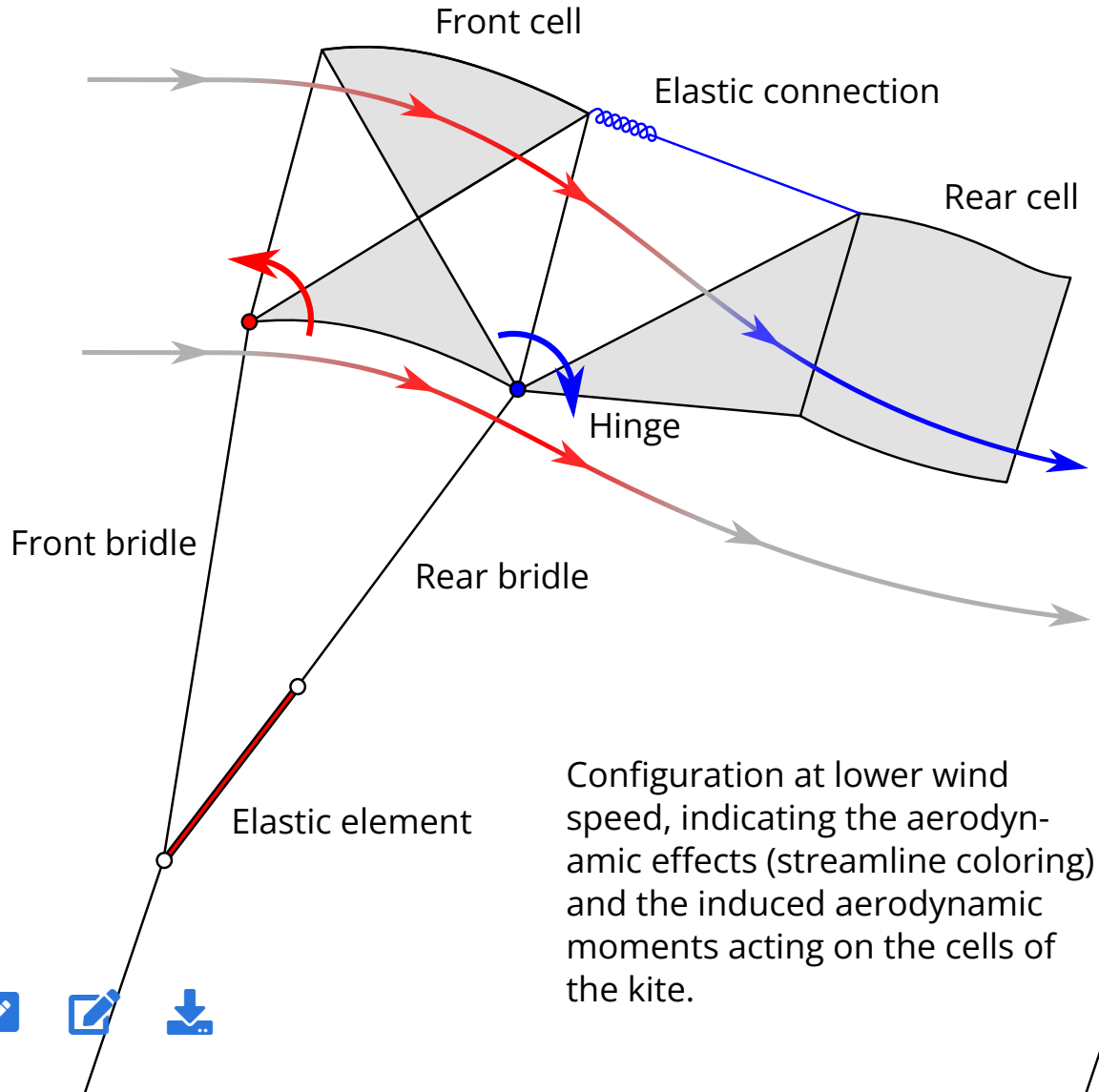
Lindenberg R-Kite



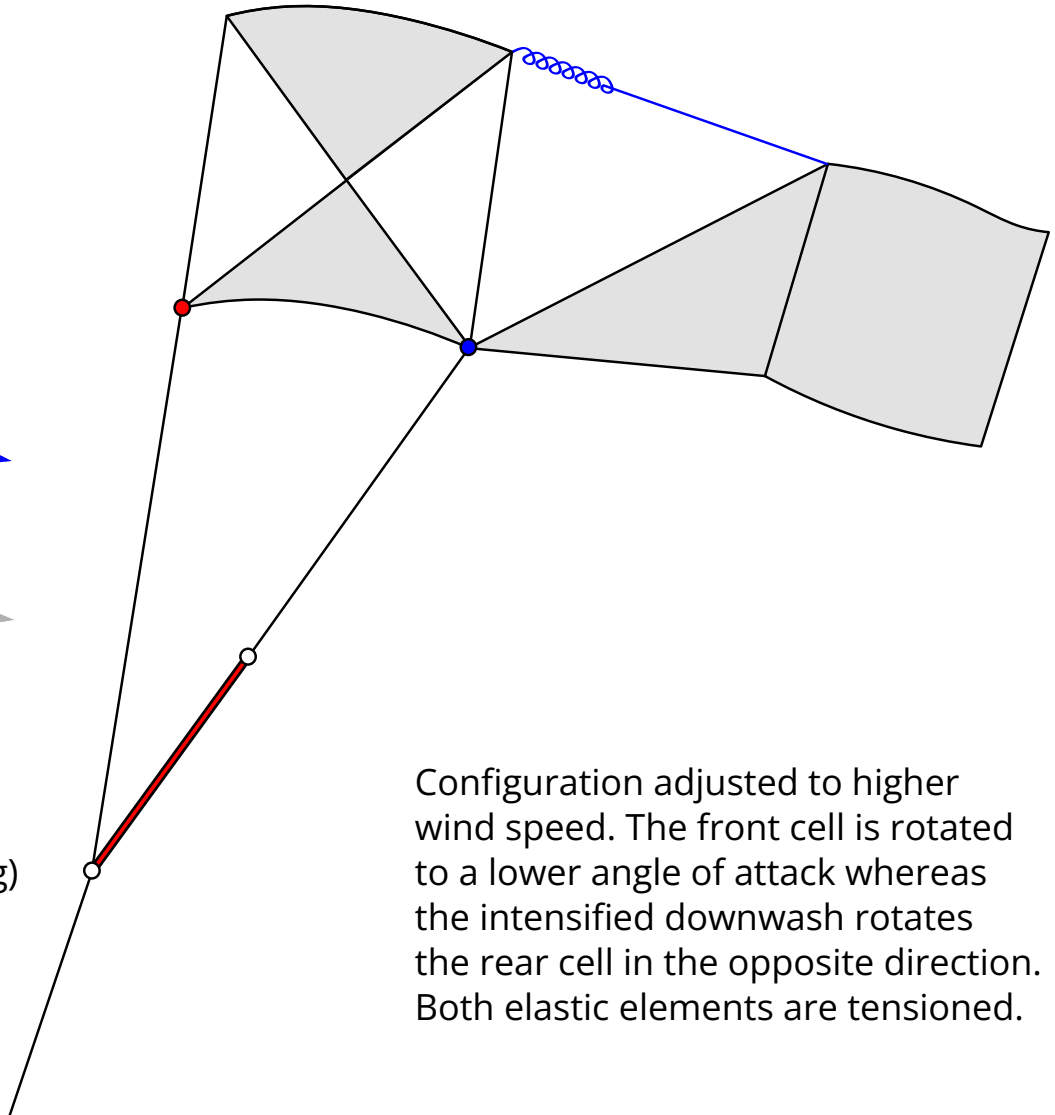


Grund (1930)

Hinged two-cell kite depower mechanism



Configuration at lower wind speed, indicating the aerodynamic effects (streamline coloring) and the induced aerodynamic moments acting on the cells of the kite.



Configuration adjusted to higher wind speed. The front cell is rotated to a lower angle of attack whereas the intensified downwash rotates the rear cell in the opposite direction. Both elastic elements are tensioned.

Lindenberg R-Kite 1989



Peter and Anne Whitehead

Lindenberg R-Kite

Maiden flight of a restored 32 m2 Lindenberg R-Kite on Fanø in 2009



Werner Schmidt/wetterdrachen.de

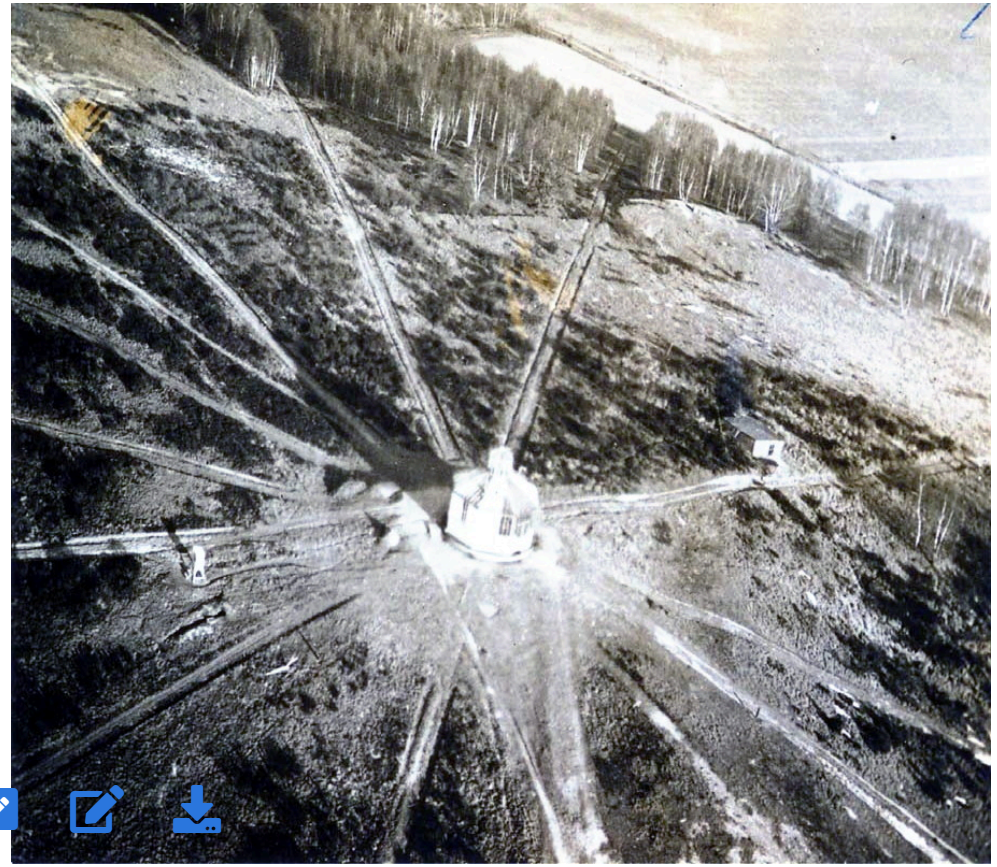
Lindenberg R-Kite



Werner Schmidt/wetterdrachen.de

Lindenberg observatory (1930)

- Most advanced observatory using kites
- 50 km SW of Berlin, Germany
- Fully 360° rotatable winch house
- Two flights per day





Altitude world record with kites (1919)

At Aeronautical Observatory Lindenberg (1914-1931)
with tethered ascends achieved heights in m

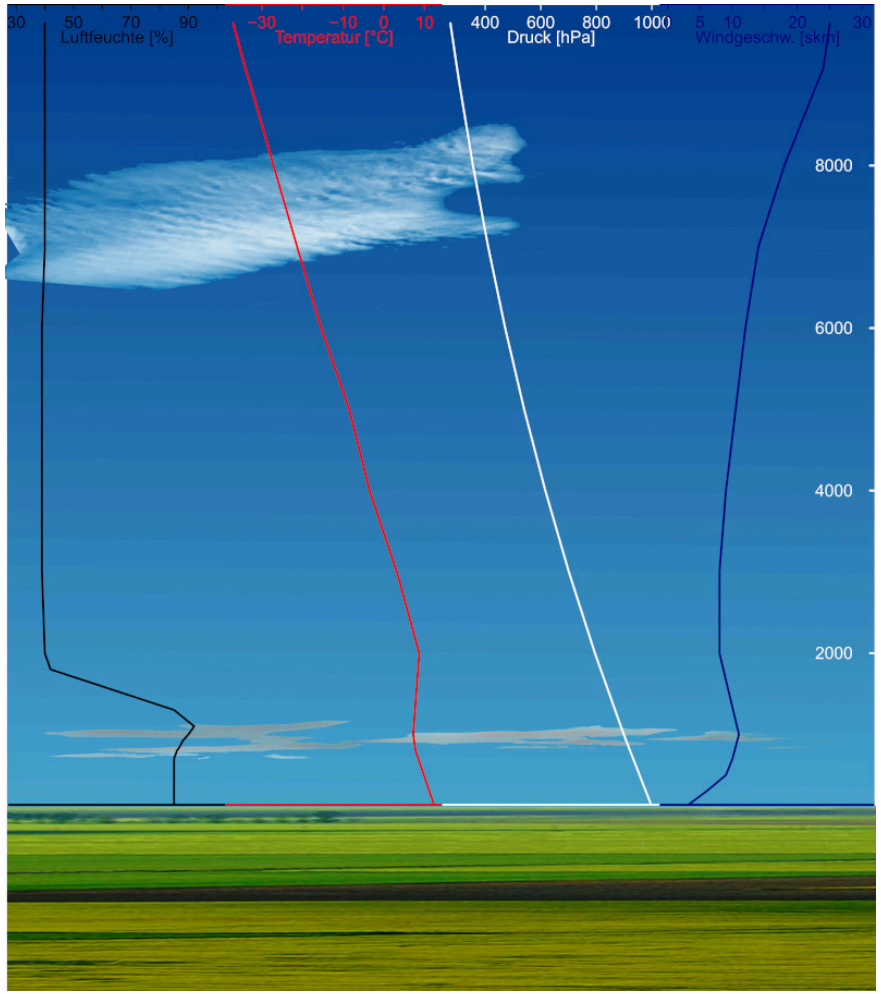
Year	with kites			with tethered balloons		
	Number	Max. height	Mean daily height	Number	Max. height	Mean daily height
1914	778	6200	3340	454	8000	3668
1915	701	5610	3517	439	5500	3089
1916	755	7500	3998	400	9200**	4332
1917	720	8240	4025	360	8500	4160
1918	703	7305	3661	312	3990	2869
1919	601	9750*	3811	182	5334	2484
1920	697	6700	3306	91	3950	2427
1921	711	5710	2968	30	2560	1867
1922	697	5860	2880	—	—	—
1923	630	4720	2560	55	4080	1677
1924	410	4660	2800	203	3260	2089
1925	456	4470	2488	166	4270	2462
1926	431	5403	2551	203	4788	2384
1927	461	4708	2535	222	4219	2182
1928	508	4260	2321	320	4070	2309
1929	703	5705	2308	220	4175	2567
1930	640	5865	2553	233	4421	2594
1931	609	5772	3030	142	4131	2385
1914–1931	11211			4023		

*) 1.8.1919 9750 m anomaly

*) 26.9.1916 9200 m!

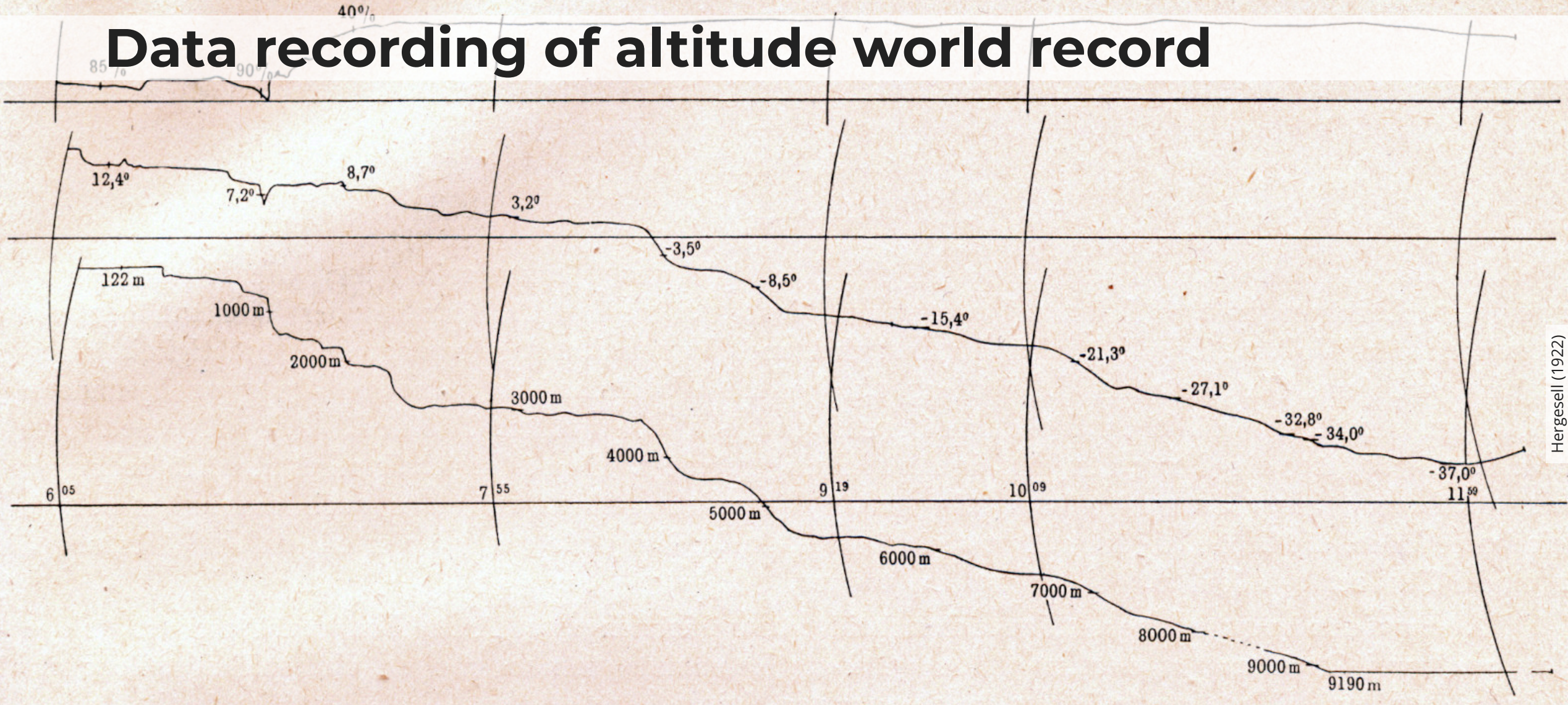
Altitude world record with kites (1919)

- The altitude record was achieved with a train of eight Lindenberg S-Kites, developed by Herrmann Schreck
- The S-Kite showed better flight behavior than the N-Kite
- 15,000 m steel wire, 0.6 to 1.0 mm thick were deployed
- Eight kites with 10, 8 and 5 m^2 wing surface area were used



Data recording of altitude world record

Fig. 8.



Hergesell (1922)

Drachenaufstieg **21** vom 1. August 1919, der höchste in Lindenberg.

Registrierung von Feuchtigkeit, Temperatur und Luftdruck auf die Hälfte der natürlichen Größe verkleinert.

Altitude record celebration (1919)

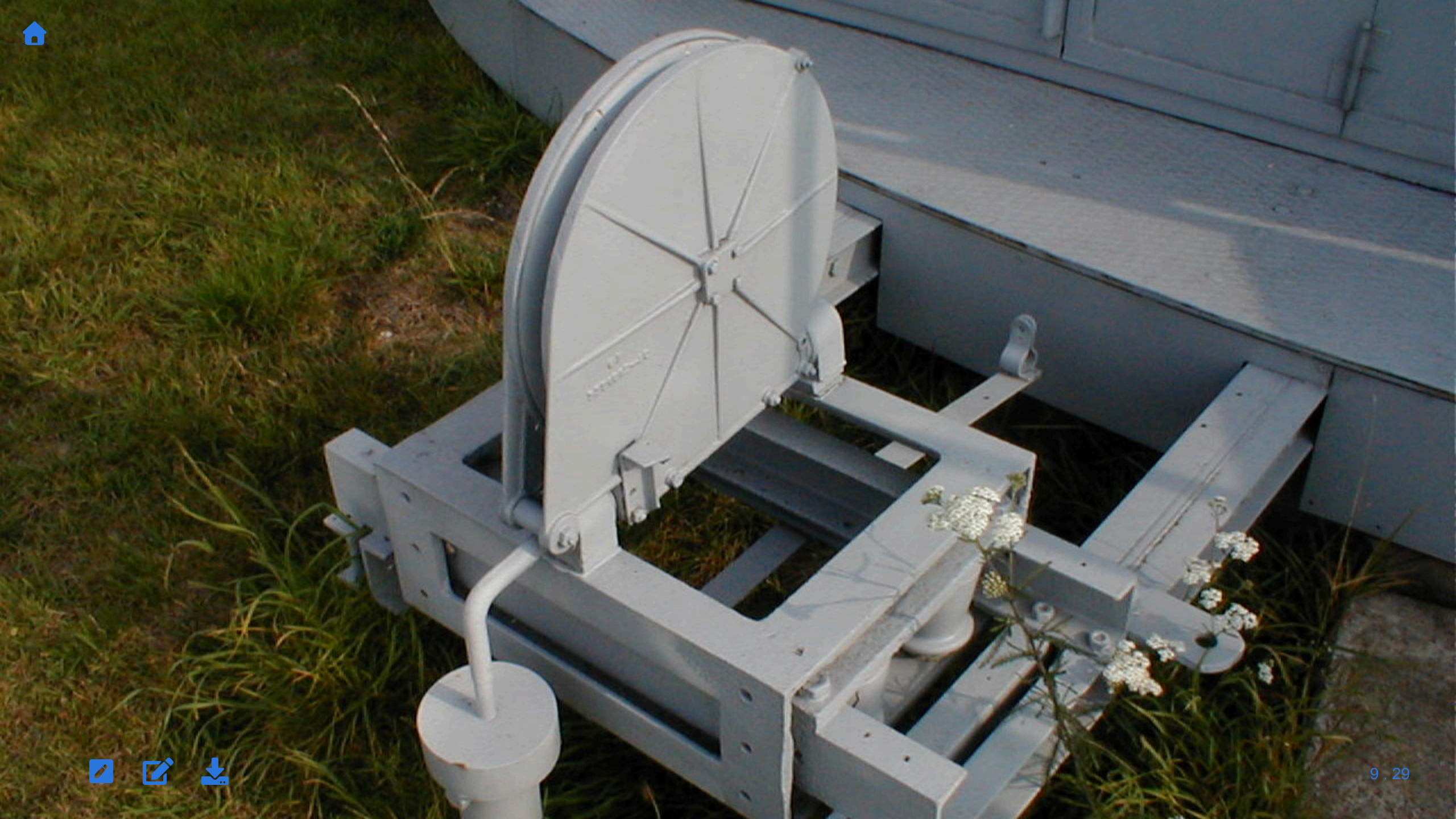


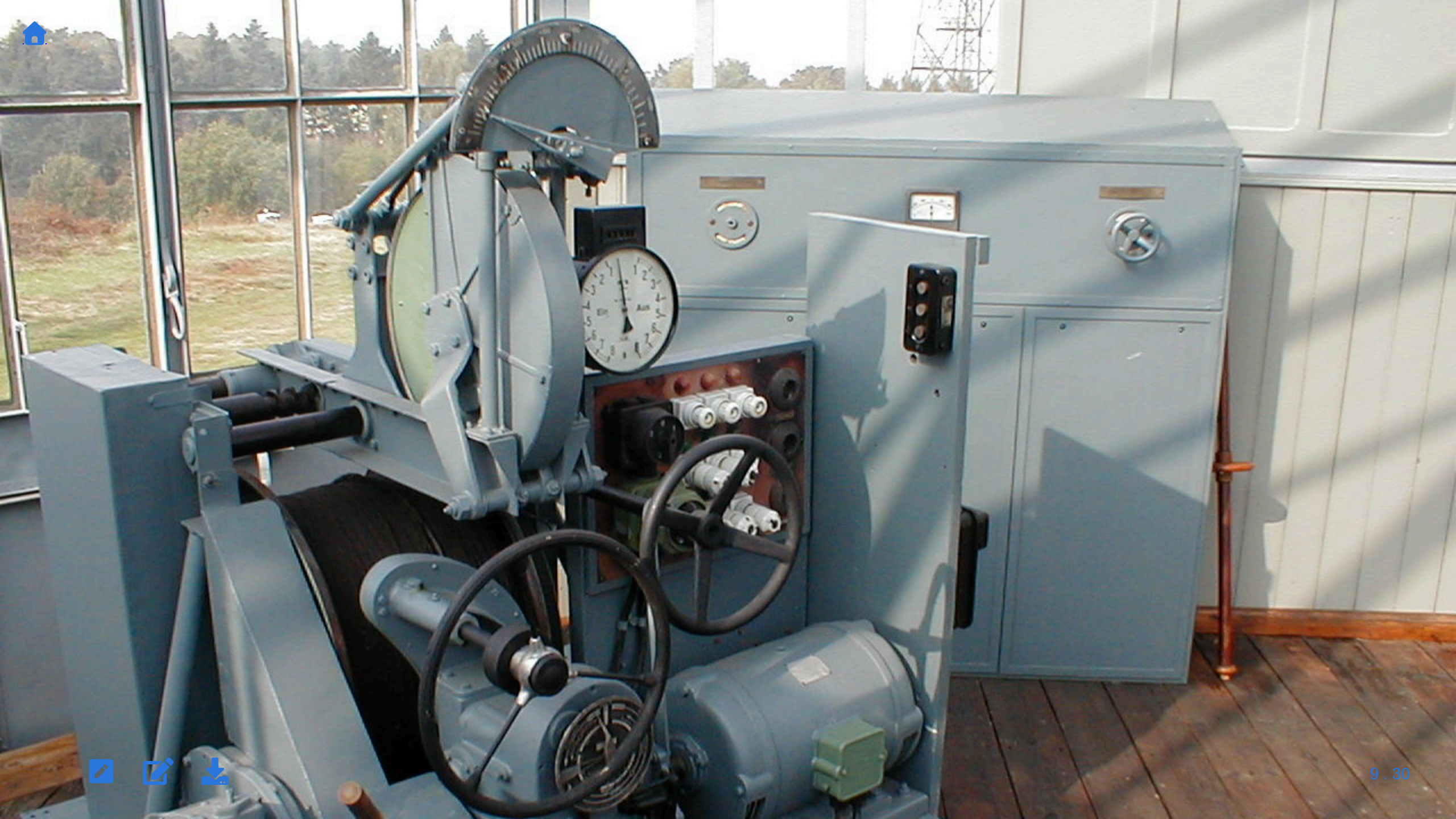
Werner Schmidt/wetterdrachen.de

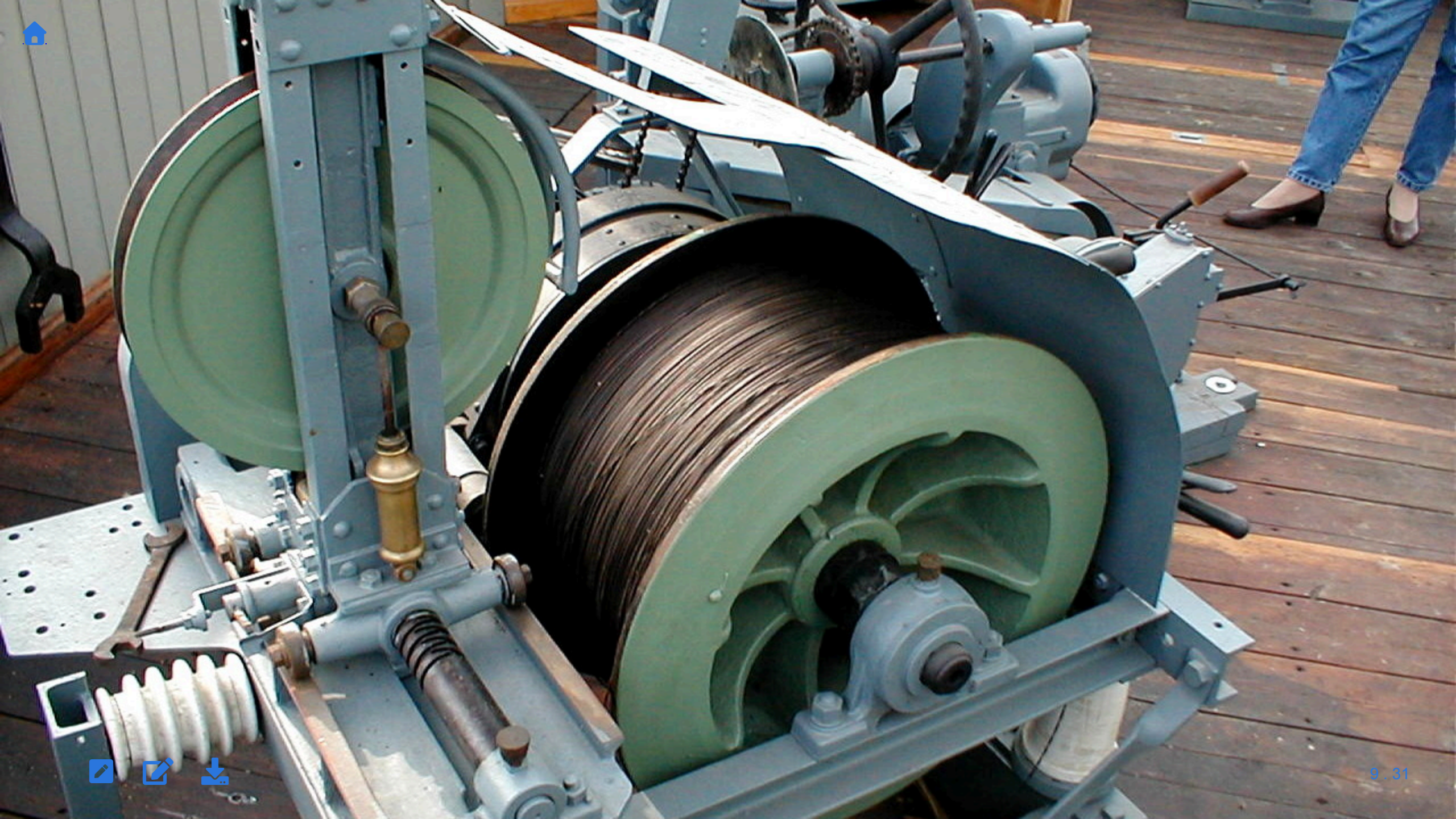
Winch house

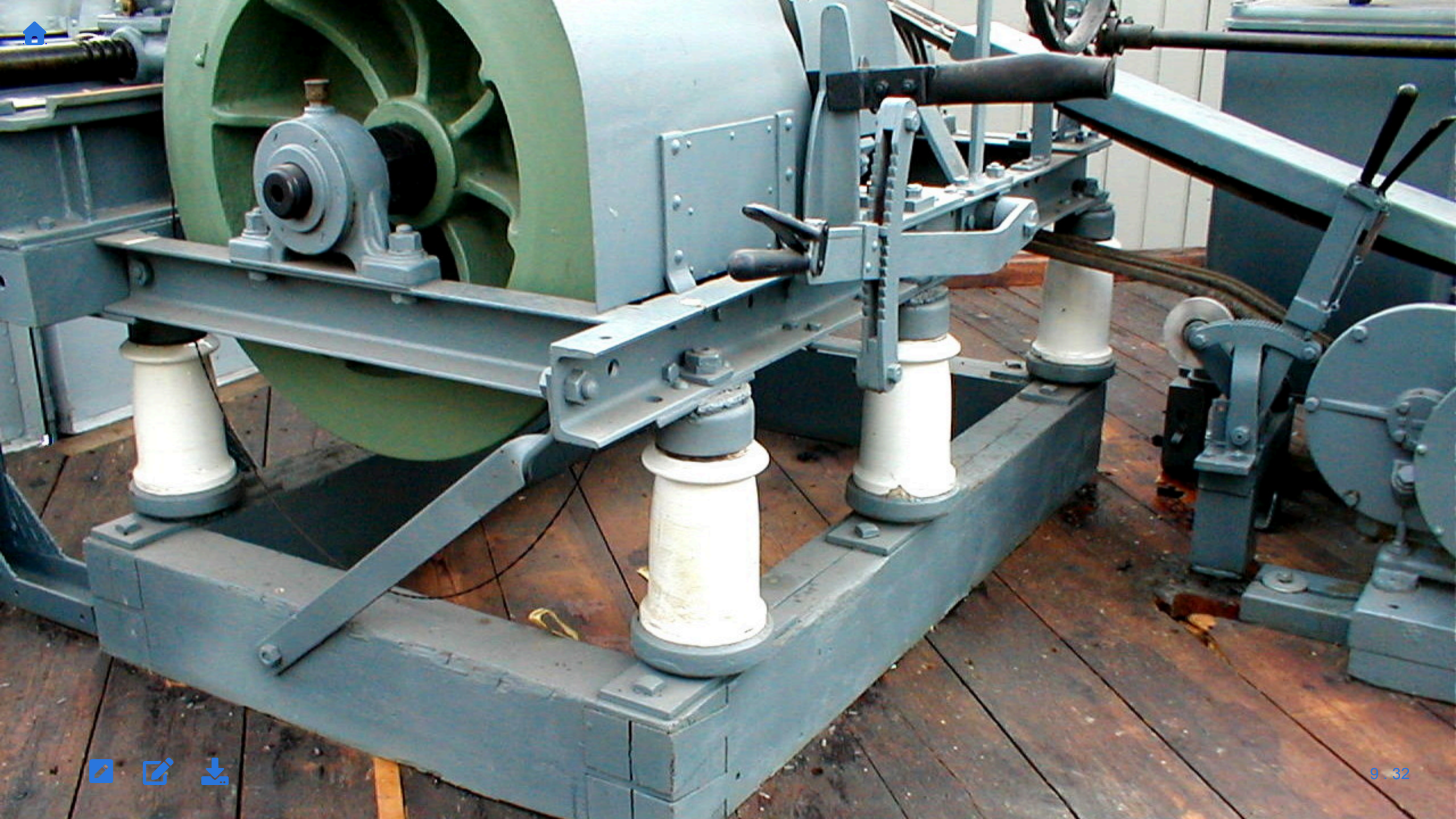
Photos by Werner Schmidt on 5 October 2000.

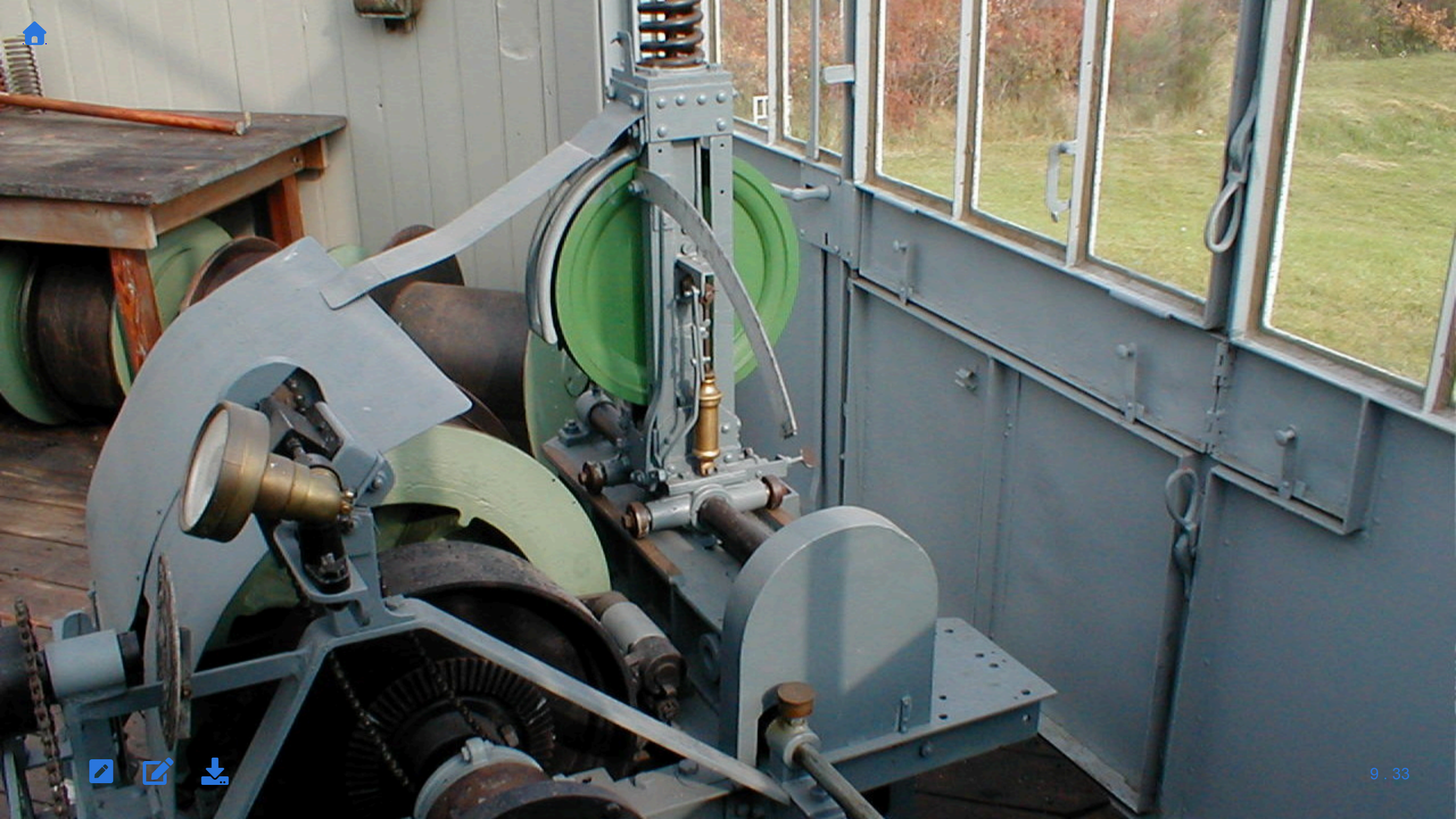


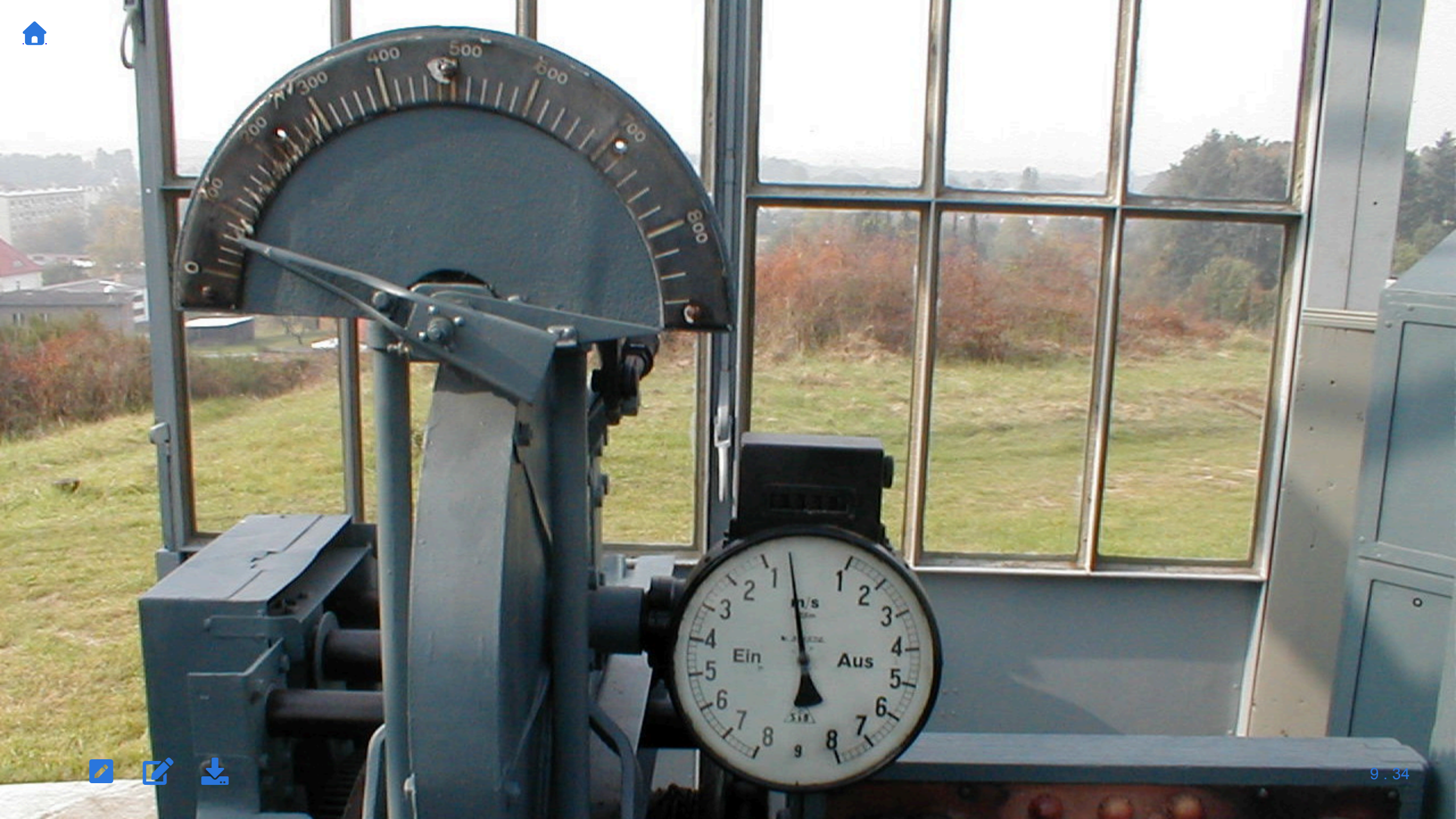











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100
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m/s
Ein
Aus

Discontinuation of kites for meteorology

- By around 1930, airplanes were considered more efficient for acquiring meteorological data (Ricker 1931)
- As consequence, kite-based measurements were more and more discontinued

Further reading

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- Millet, J.B.: Scientific kite flying, with special reference to the Blue Hill experiments. The Century illustrated monthly magazine, Vol. 54, pp. 66-77 (1897).
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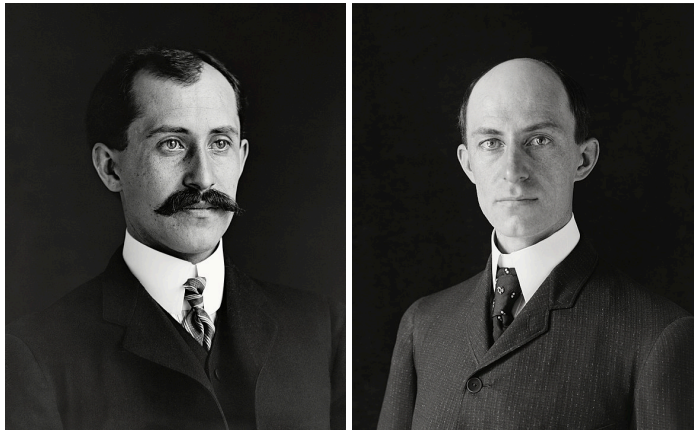
Precursor for powered flight



Library of Congress

Wright brothers first flight, 120 feet in 12 seconds, 10:35 a.m., 17 December 1903; Kitty Hawk, North Carolina.

Wright brothers kites



Orville and Wilbur Wright in 1905

Library of Congress

- The **Wright brothers** were American aviation pioneers generally credited with inventing, building, and flying the world's first successful motor-operated airplane.
- In 1899, Wilbur built a biplane kite to test whether **warping the wings** would roll the craft right and left. The kite was controlled from the ground by four cables attached to two sticks.
- The brothers originally referred to this as wing twisting, but Octave Chanute later dubbed it "wing warping" and the name stuck.
- The kite had a small horizontal tail attached to back middle strut. This was the last flying machine built by the Wrights to have a horizontal tail in the back until over a decade later, when the Wright Company began to manufacture the Wright Model B airplane.

1899 Wright Kite

Reproduction

- Biplane kite with 1.5 m wingspan



Smithsonian - National Air and Space Museum

1899 Wright Kite

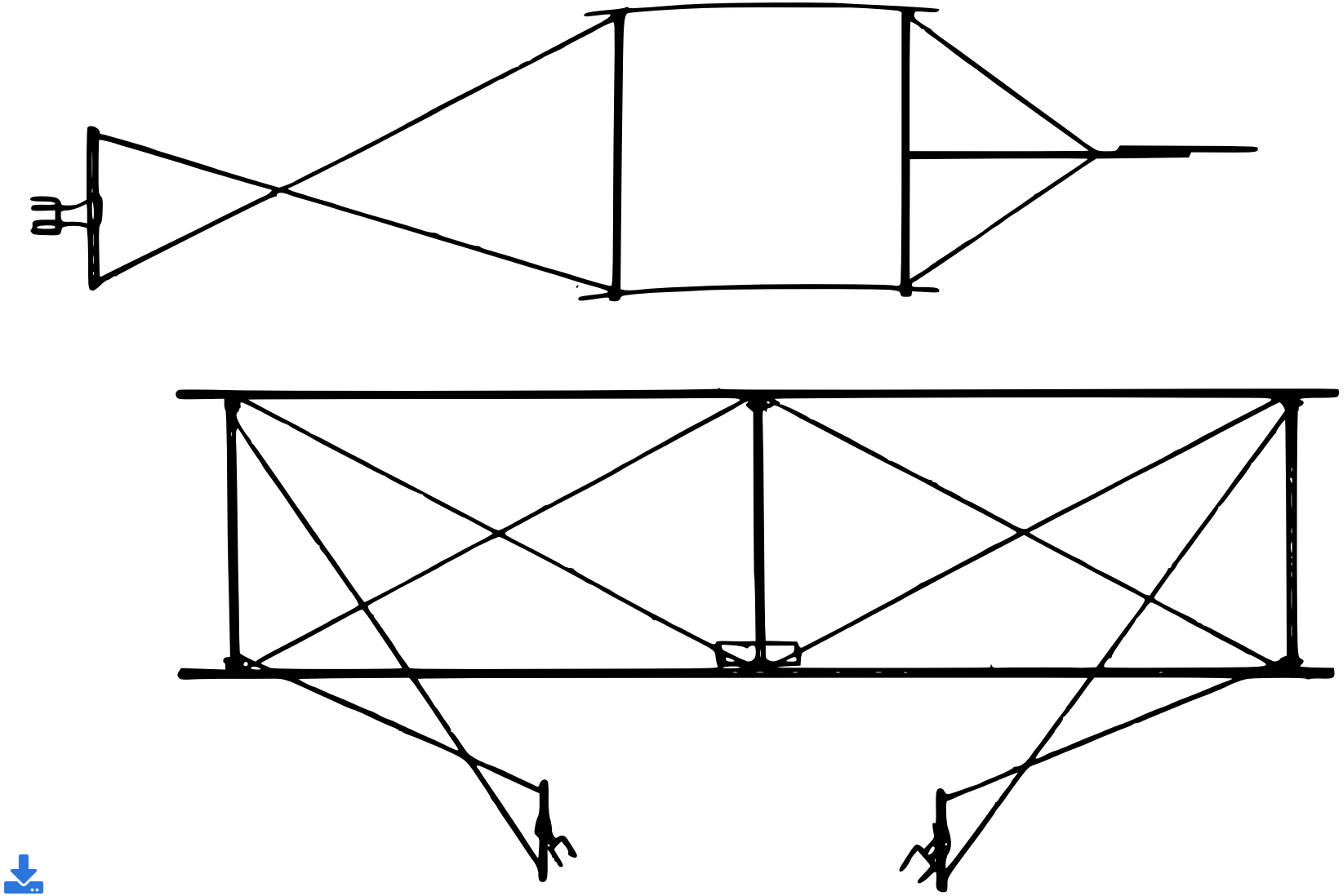
Reproduction



- Unbraced between front and rear struts to allow for wing-warping

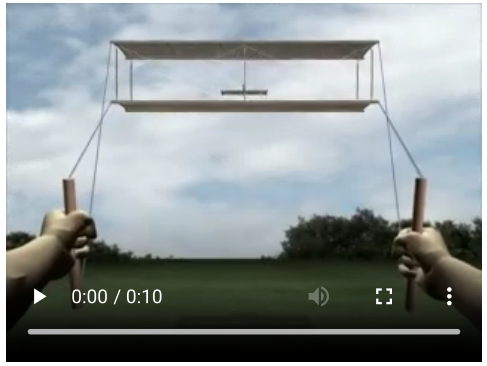
Smithsonian - National Air and Space Museum

1899 Wright Kite

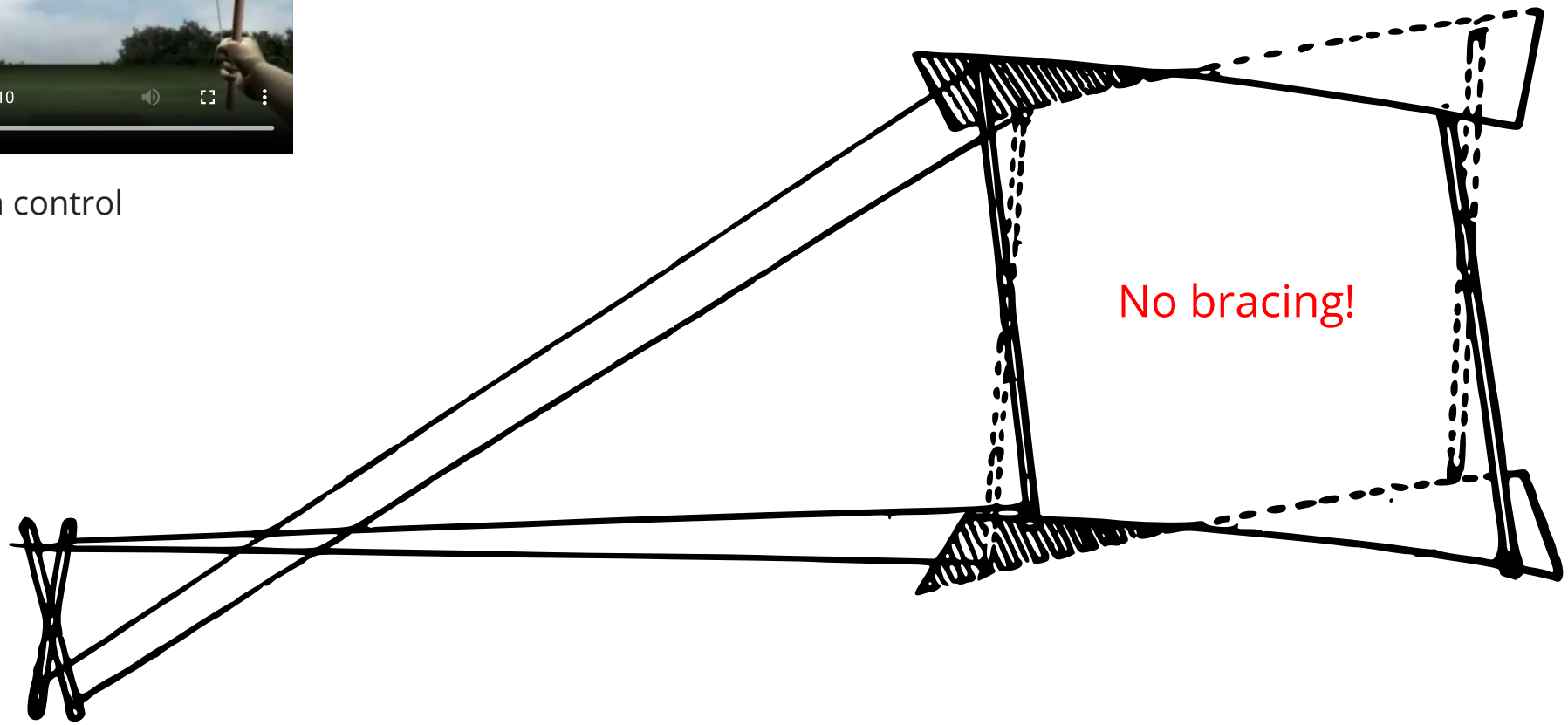


Library of Congress

Wing warping for roll control

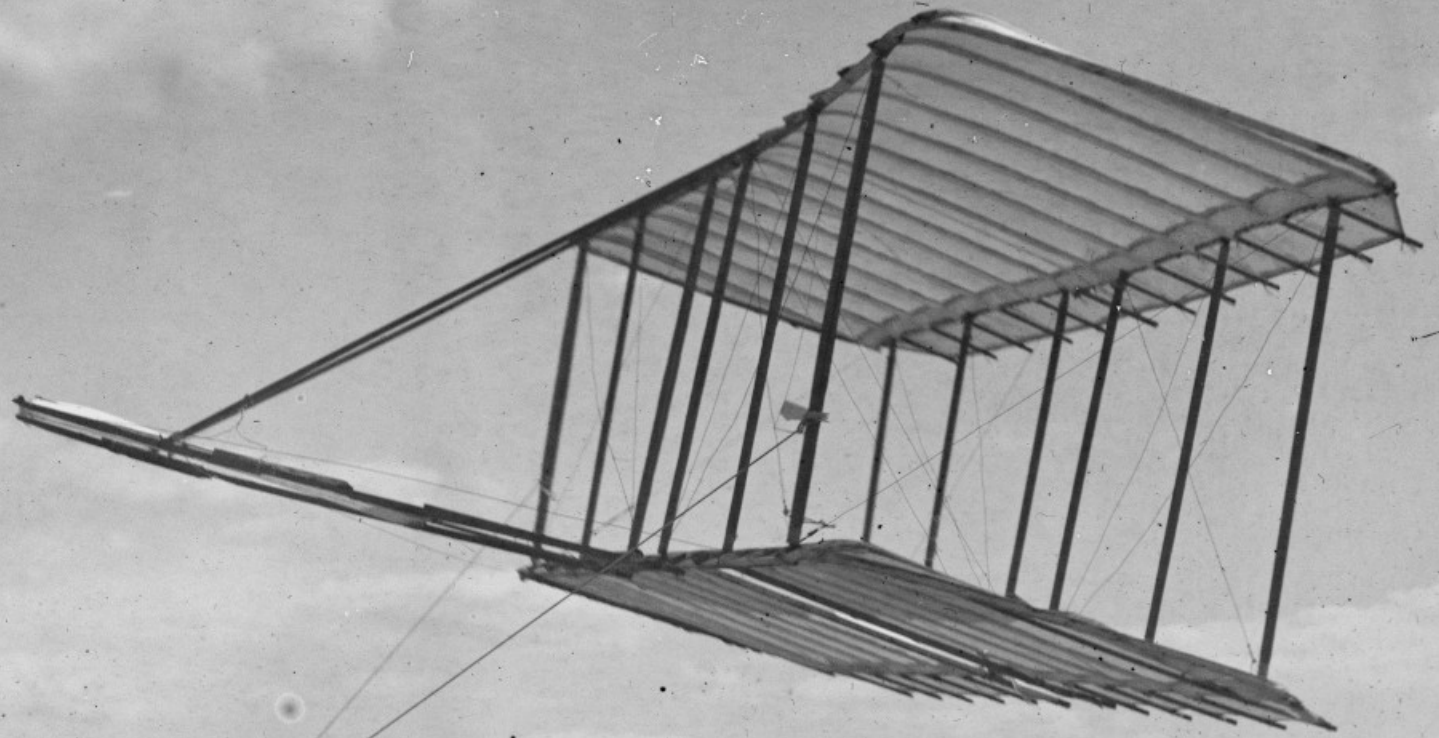


- Pitch control



Library of Congress / animation by Clifford Barton

1900 Wright Glider

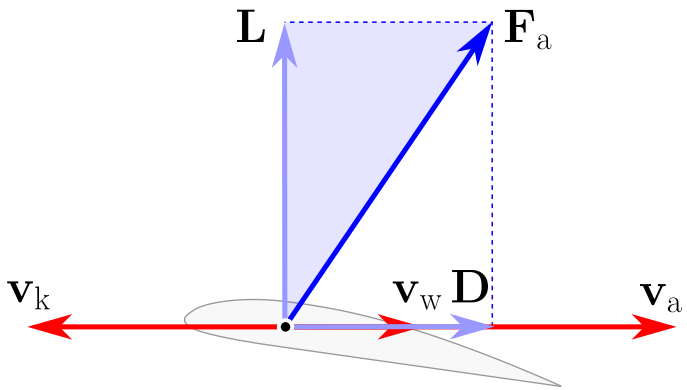


Library of Congress

Lift and drag equation (1900)

The accepted equations for lift and drag were:

$$L = kSC_{\mathrm{L}}v_{\mathrm{a}}^2$$
$$D = kSC_{\mathrm{D}}v_{\mathrm{a}}^2$$



$$\mathbf{v}_{\mathrm{a}} = \mathbf{v}_{\mathrm{w}} - \mathbf{v}_{\mathrm{k}}$$
$$\mathbf{D} \parallel \mathbf{v}_{\mathrm{a}}$$
$$\mathbf{L} \perp \mathbf{v}_{\mathrm{a}}$$

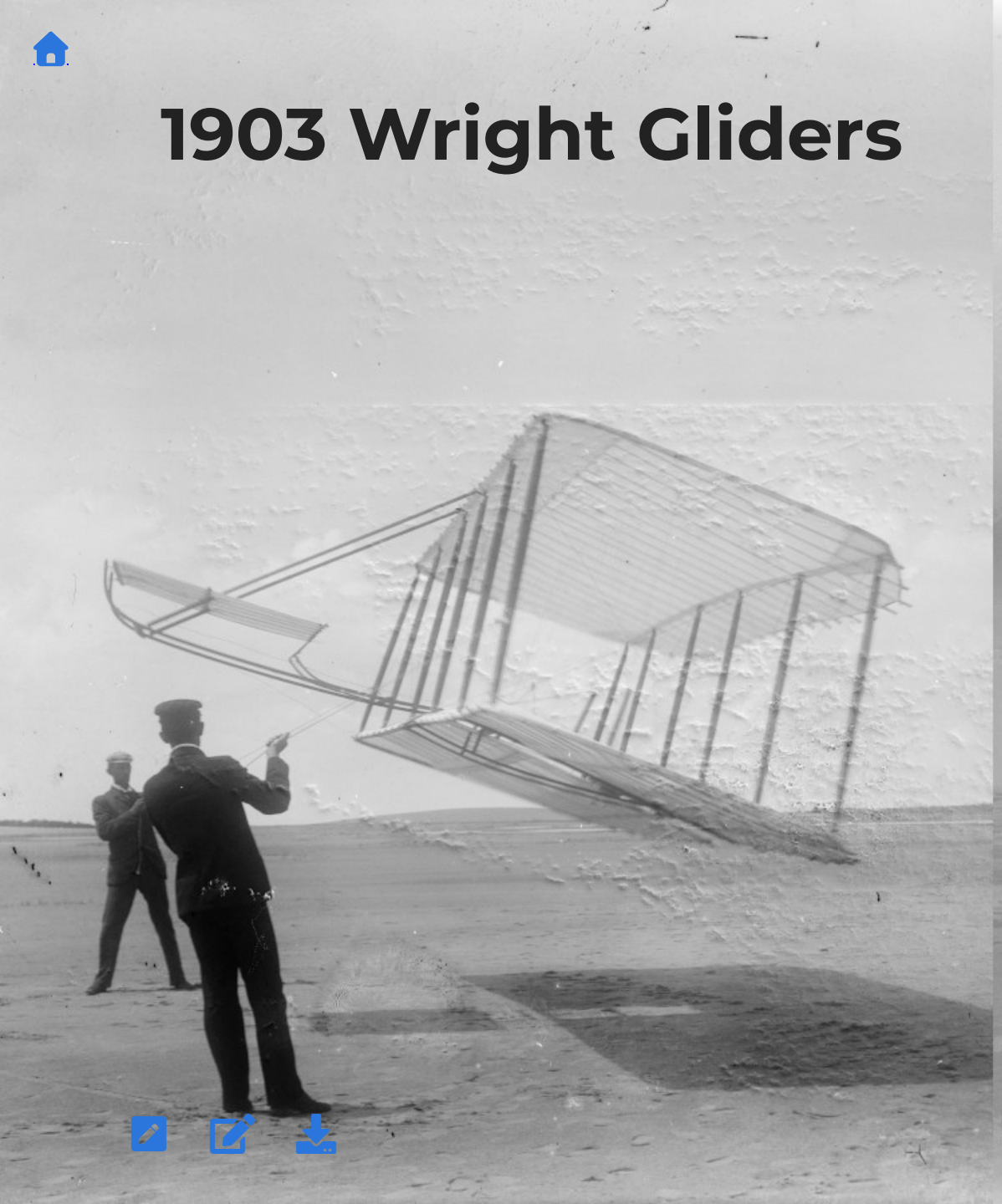
where

L and D are the lift and drag forces in pounds
k is the coefficient of air pressure (Smeaton coefficient)[1]
S is the total area of lifting surface in square feet
C_{L} and C_{D} are the coefficients of lift and drag (vary with wing shape)
v_{a} is the apparent wind velocity in miles per hour

The poor lift of the gliders led the brothers questioning the accuracy of the Smeaton coefficient, 0.005, which had been in use for over 100 years. Also doubting the accuracy of Lilienthal's lift coefficient they conducted own wind tunnel experiments.

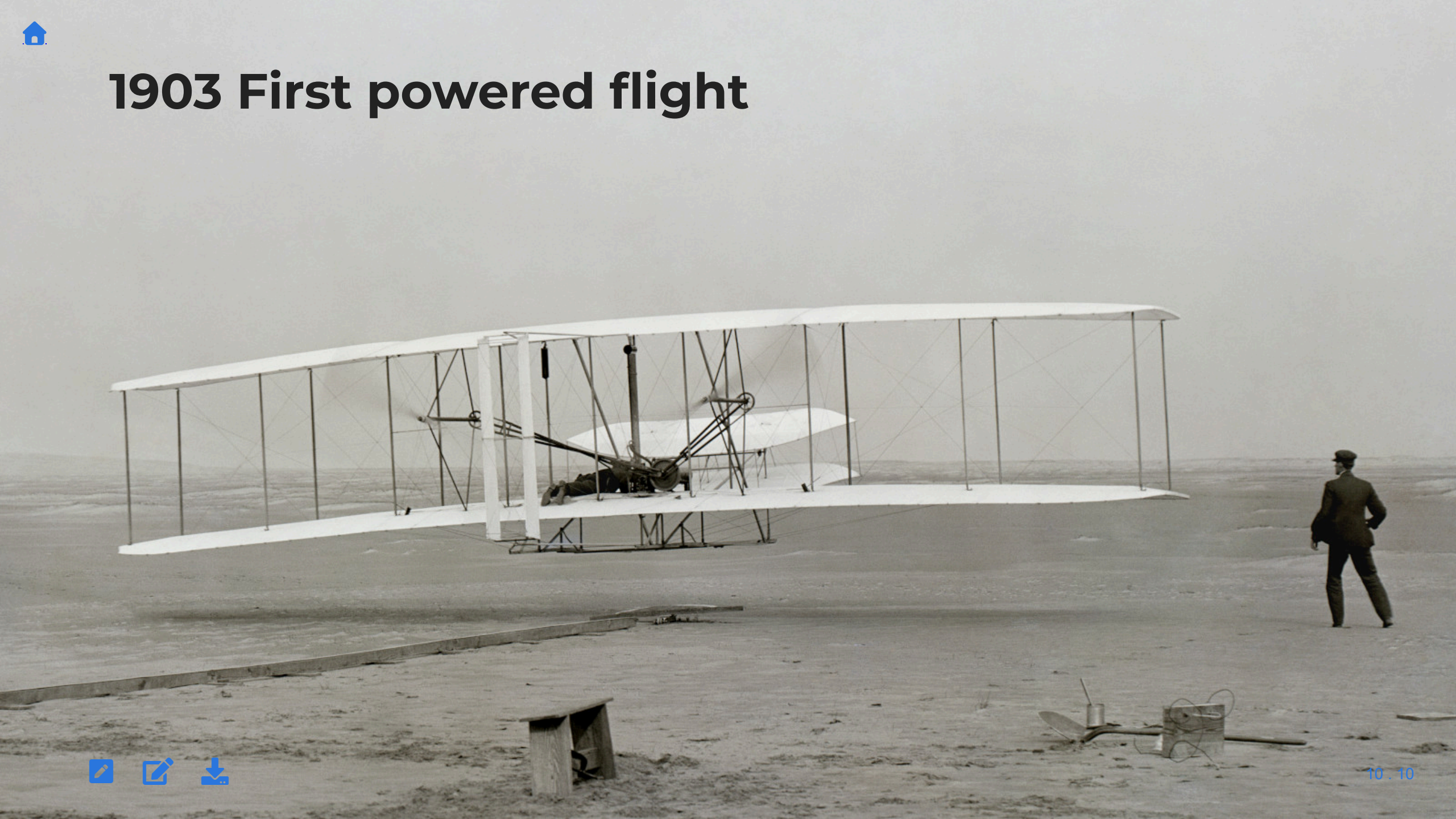
[1] In modern aerodynamic analysis, the dynamic pressure of the flow around the wing is used to describe the air density dependence.

1903 Wright Gliders





1903 First powered flight



Further reading

- Smithsonian National Air and Space Museum: Researching the Wright Way.
- Cherne, J., Culick, F., Zell, P.: The AIAA 1903 wright 'flyer' project prior to full-scale tests at NASA ames research center. In: 38th aerospace sciences meeting and exhibit, Reno, NV, USA 2000. doi:10.2514/6.2000-511

Rediscovery for power generation



Photo by Bryan Roberts, provided by PJ Shepard

Prototype testing the flying electric generators in Australia in May 1986.

The visionaries

- Aloys van Gries (1935): Wind power machine carried by kites
- Hermann Oberth (1977): Kite power plant
- Miles L. Loyd (1980): Crosswind kite power
- John F. Wellicome (1984): Ship propulsive kites
- Bryan Roberts (1986): Flying electric generators

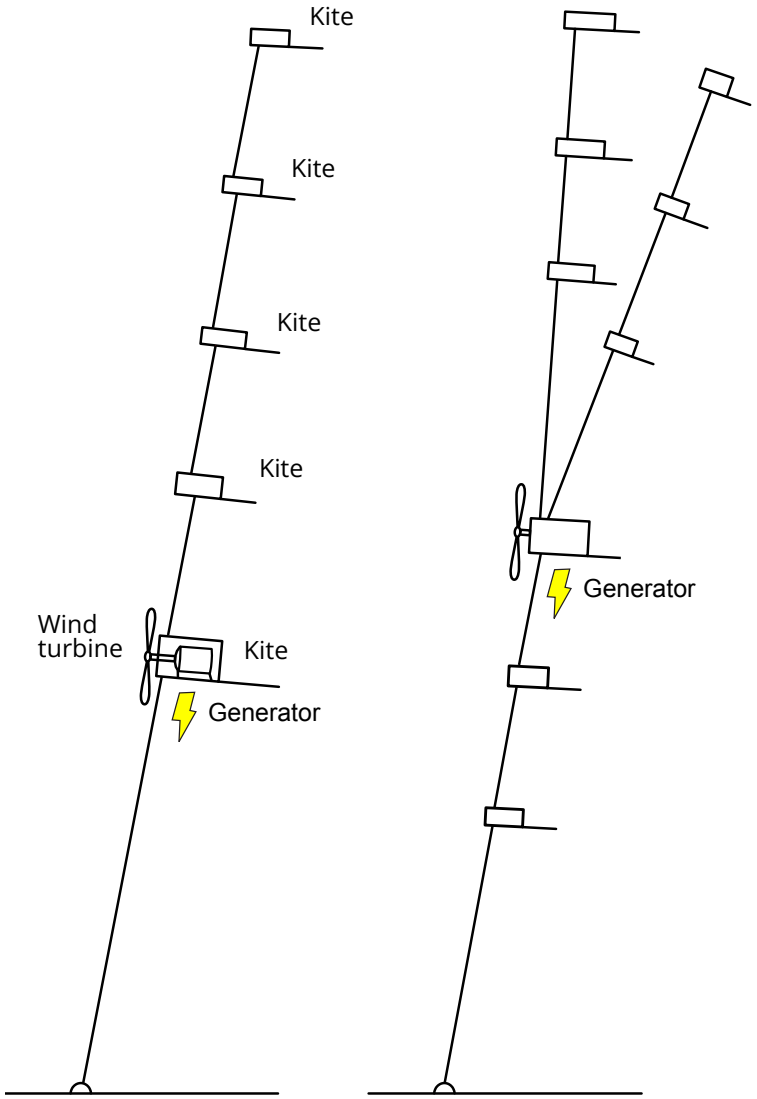
Tethered flying wind turbine (1935)

- **Aloys van Gries** headed the department of aircraft statics at Berlin Adlershof during WW1.

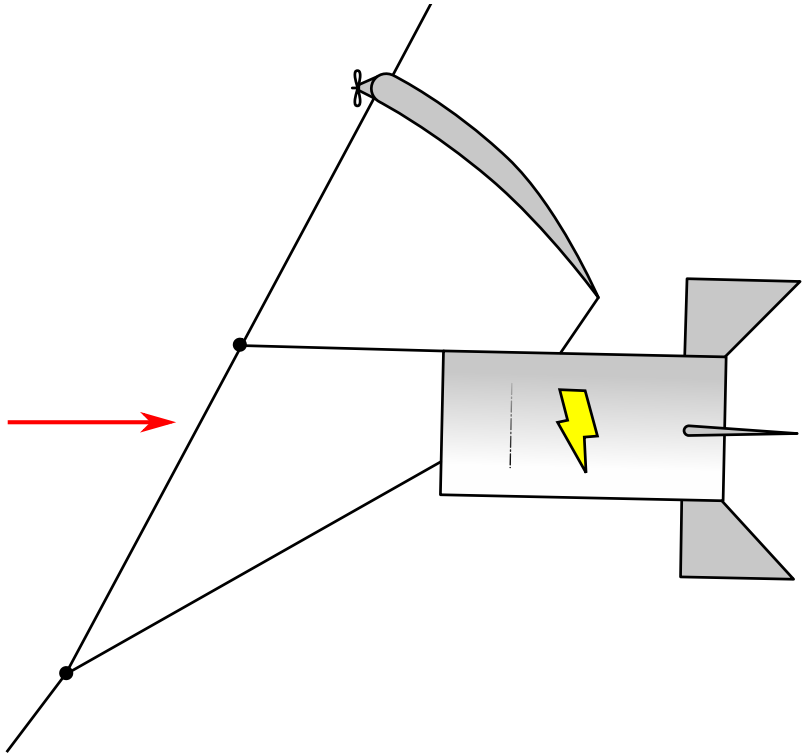
- In 1921, he published a book on **aircraft statics**.

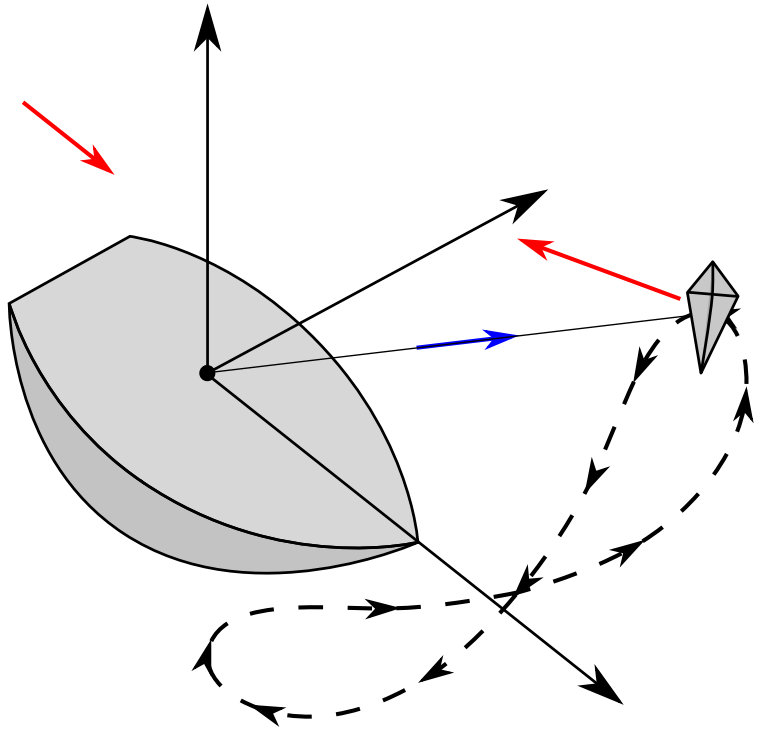
- In 1935, aged 70, he patented the concept to use kite trains to lift an onboard wind turbine to higher altitudes.

- Alternatively transfer of mechanical power to ground.
- Modified layout for higher stability.
- Patents: DE656194, FR825476, GB489139.



Oil crisis & renewable energies (1970-80)





Hermann Oberth (1977):
Kite power station
- Kite-lifted shrouded wind turbines
- Targeting also jet streams

John F. Wellicome (1984)
Ship propulsive kites
- Crosswind maneuvering kite
- Outperforms other solutions

Oberth (1977), Wellicome and Wilkinson (1984)

Crosswind kite power (1980)

- **Miles L. Loyd** was an engineer working at the Lawrence Livermore National Laboratory, working since ~1975 on fossil fuel alternatives.
- He realized that the **jet stream moved around** too much to be a useful source of energy.
- Instead, he focussed on the altitudes between existing wind turbines and the jet stream to extract useful power.
- In 1980, he published the paper Crosswind Kite Power, which was one of the first theoretical works describing the use of kites for harnessing wind energy.
- Although highly idealized, the **analytical model** remains an important foundation for follow-up models, where many of the assumptions have been relaxed for higher accuracy.
- In 1981, he filed for a patent, US4251040A.

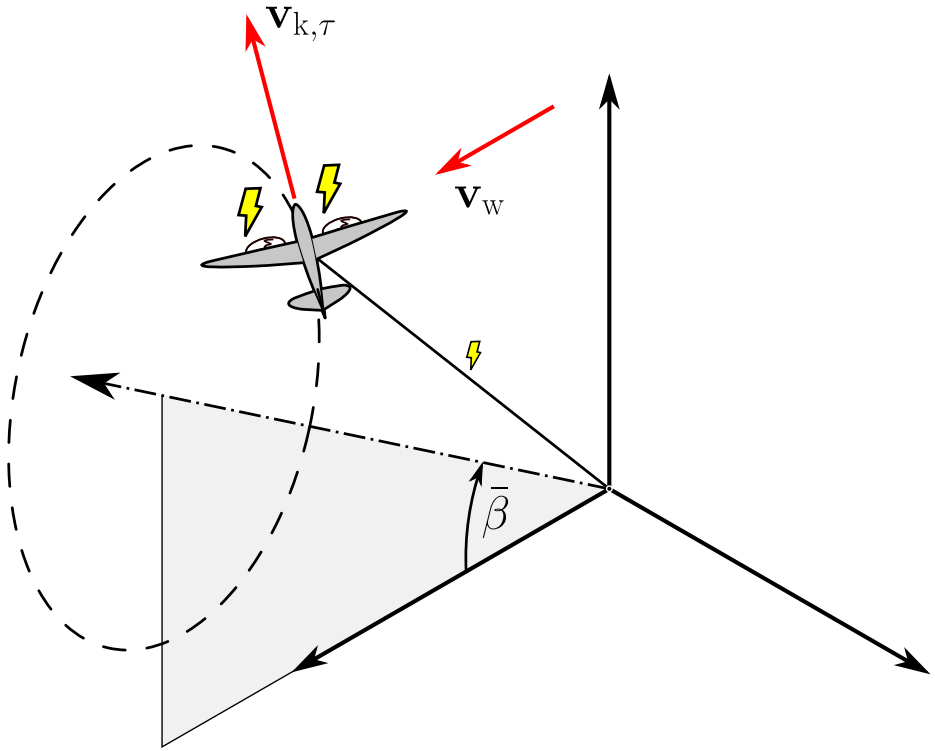


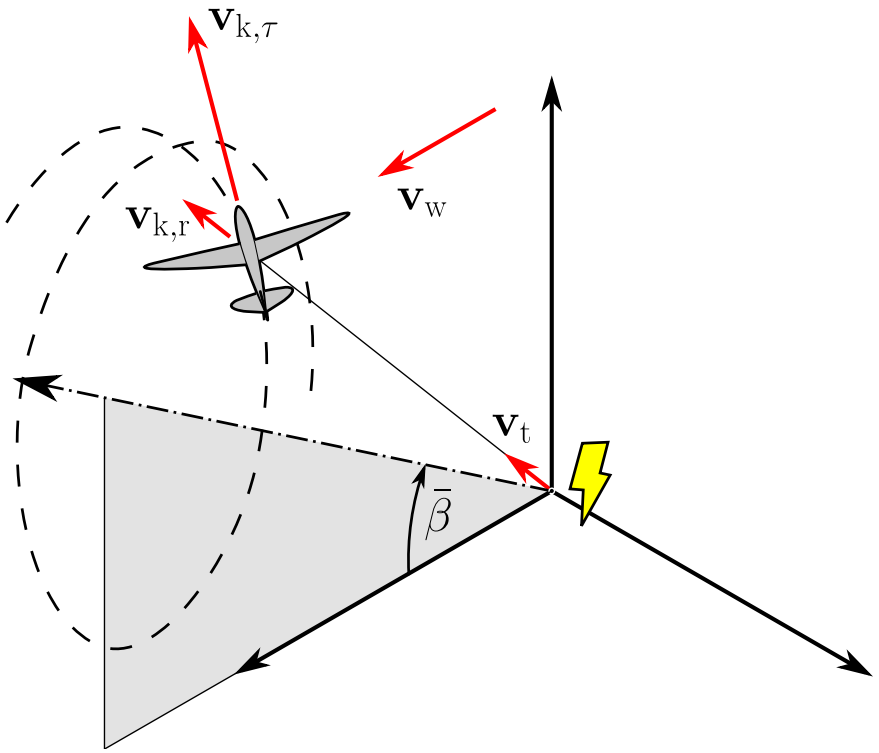
Miles L. Loyd (1932-2022)

Miles L. Loyd visiting a test of Makani's Wing 4 prototype in 2010.

Airborne vs ground-based conversion

awesco.eu/awe-explained/





Airborne energy conversion:

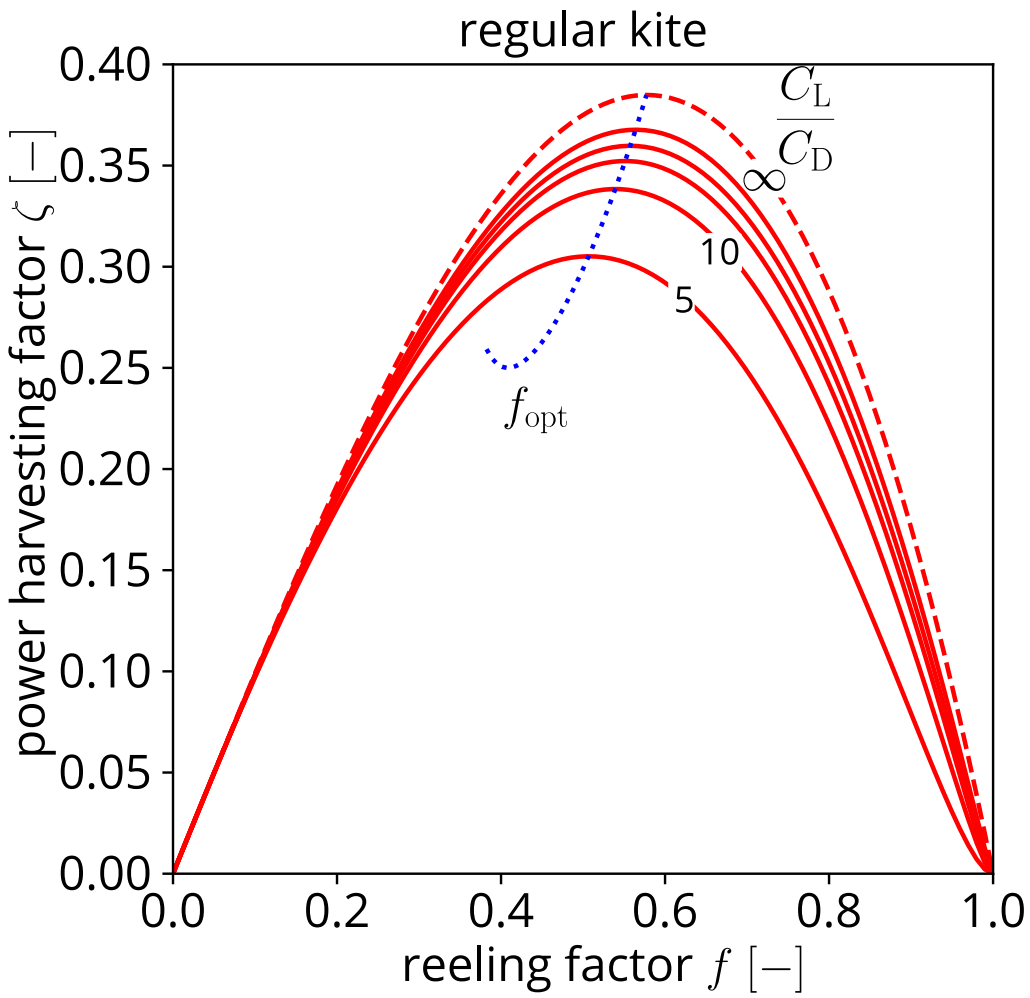
- Flying wing ⇝ shaft power
- Shaft power ⇝ electricity ($\omega \uparrow$)
- Electricity ⇝ conductive tether

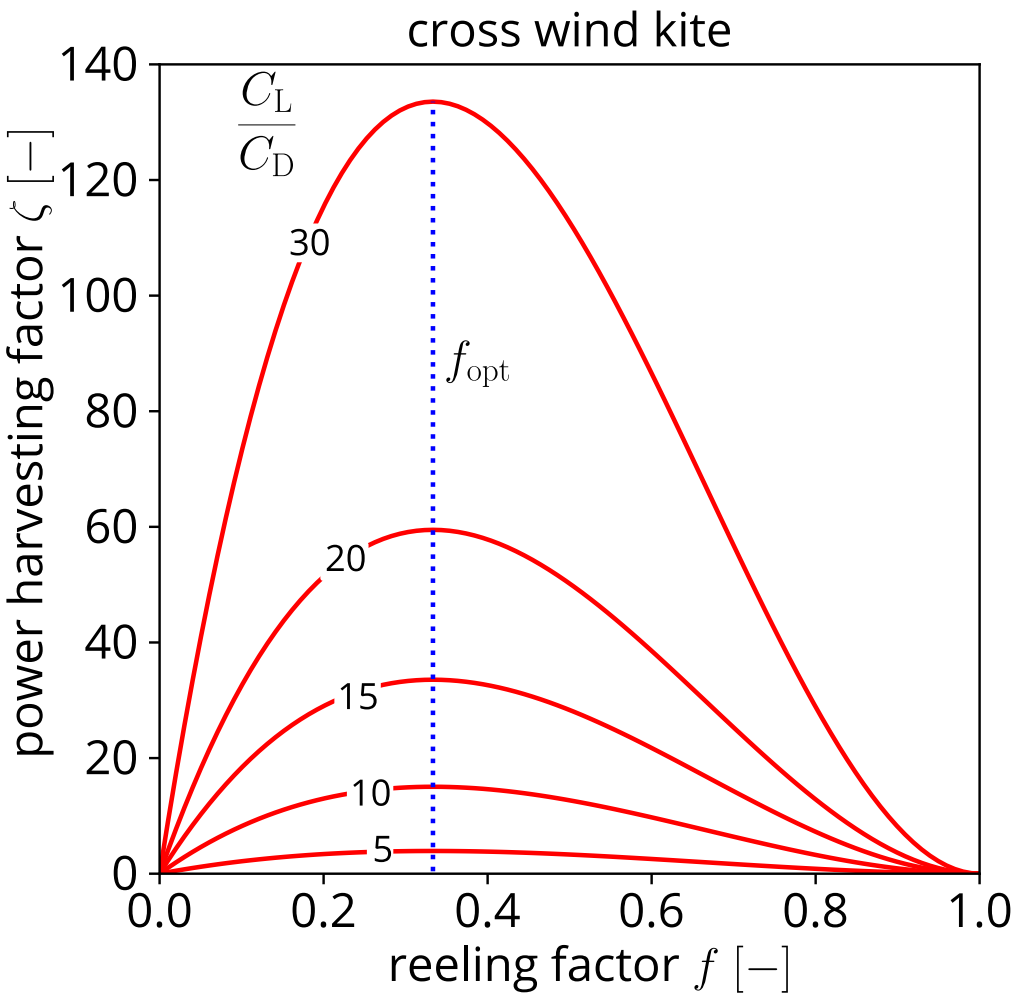
Ground-based energy conversion:

- Flying wing ⇝ traction force
- Traction force ⇝ shaft power ($\omega \downarrow$)
- Shaft power ⇝ electricity

Regular vs crosswind kite

awesco.eu/awe-explained/





Loyd’s hardware



Loyd’s testflights



Loyd’s son, David, flies the kite in 1982 for the Smithsonian magazine.

Rediscovery for sports



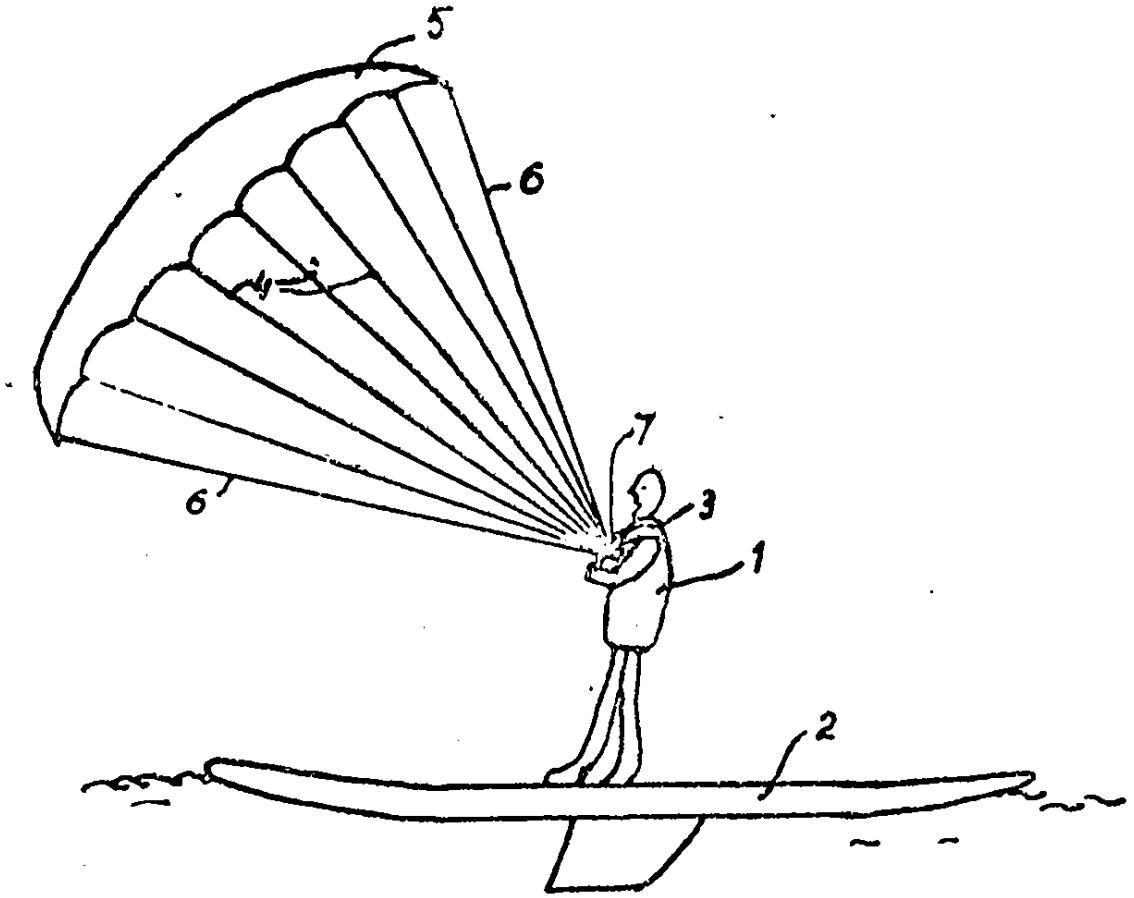
Wissant, France, 2020

Timeline

- Mid-1980s – Late 1990s: **Early Inflatable / C-Kites**. **Arc-shaped** profile, direct line attachment, high power but **zero de-power** ability. Unforgiving and dangerous.
- Late 1990s – Early 2000s: **Refined C-Kites & 5-Line Kites**. Square-cornered “C” shape, addition of a **5th line** for easier water relaunch and safety sheet-out.
- 2005 – Present: **Bow Kites & Hybrid Kites**. **Swept-back wingtips**, flatter profile, and bridle systems. Allowed up to **100% de-power**, drastically improving safety.
- Late 2000s – Present: **Delta Kites & Open-C Kites**. Triangular, swept back shape. Combines high performance of C-kites with safety and easy relaunch of Bow kites.
- 2010s – Present: **Modern Foil Kites & Foil Wings**. Double-skinned, **ram-air cell** design adapted for water. Highly efficient for light-wind hydrofoiling.
- 2015 - Present: **Single Skin Kites**. Airfoil shape generated by battons integrated into leading edge membrane. For low wind and mountaineering due to low weight.
- Present: **Hybrid kites**. Combining ram-air leading edge cell with single skin canopy.

First kitesurfing patent (1977)

- Dutch inventor **Bert Panhuise** can be credited with the first kitesurfing patent.
- Although the patent decribed all aspects of the sport, it did not trigger commercial interest.



Patent NL7603691A

First kiteskiing patent (1976)

- **Dieter Strasilla** developed parachute- and kite-skiing systems.
- The development of the **Skywing** was heavily influenced by and derived from actual NASA space-recovery technology.
- Moving from parachute- to parawing designs enabled skiers to ascend using wind power and launch into controlled flights from mountain ridges.





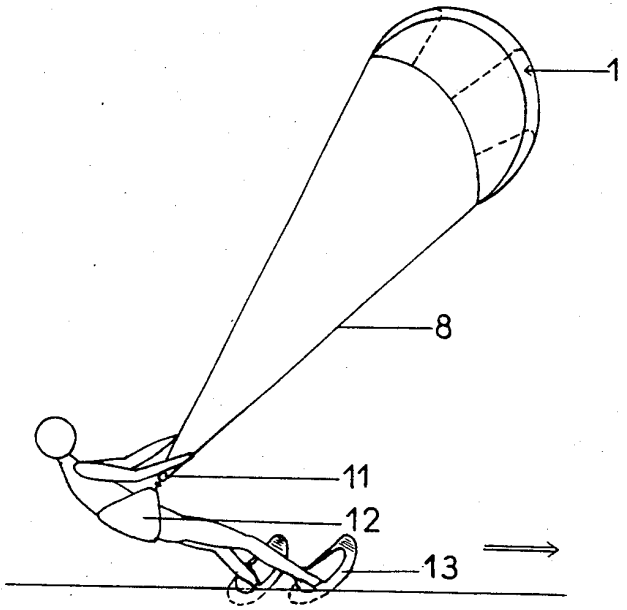


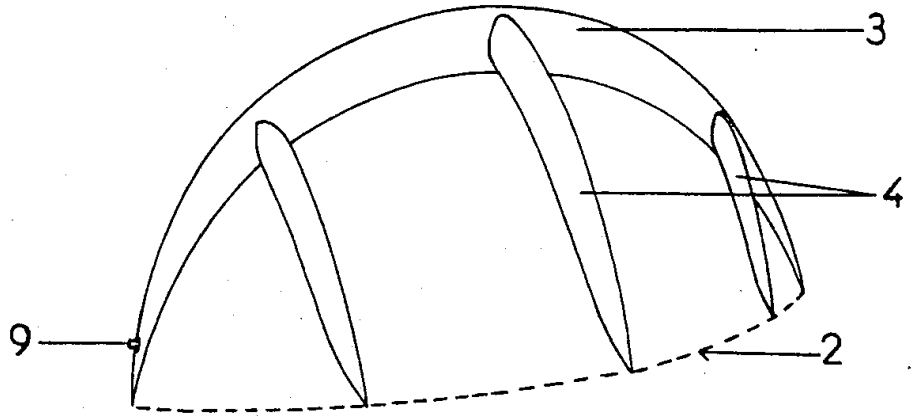
Dieter Strasilla

Parachute sailing in the Swiss Alps, 1976 or 1977.

Kitesurfing pioneers

- Bruno and Dominique Legaignoux (1984): Patented an inflatable kite design





Legaignoux and Legaignoux (1984)

Inflatable surf kites



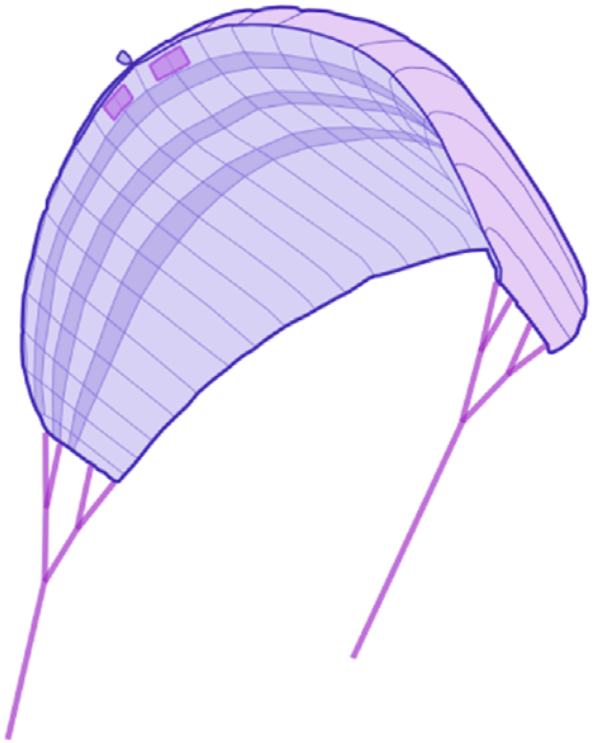
First test of a C-kite by the brothers Legaignoux (1984)



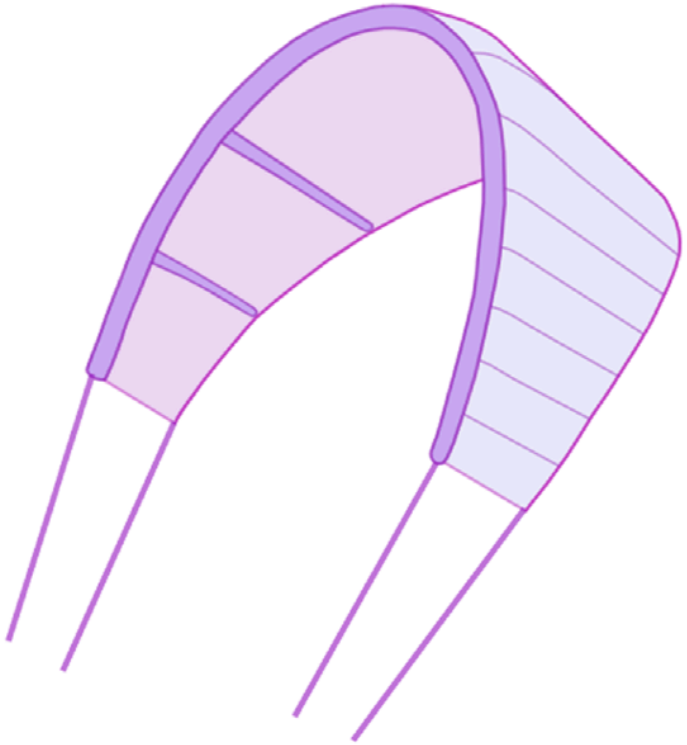
Bruno and Dominique Legaignoux participate in the Windsurfing World Cup, La Torche (1986)

Wikimedia, Ouest-France

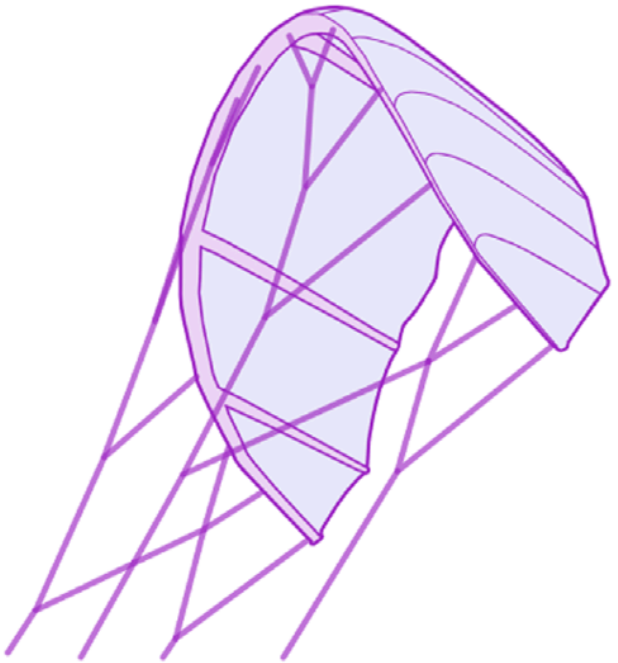
Inflatable surf kite evolution



C kite



4-line C kite



Bow kite

Kite surfing now

- 2022: kite market was valued at approximately US$ 1.59 billion
- 2023: projected expansion to US$ 2.20 billion



Kiteboarding at the Dutch coastline in 2022

Jelle Poland



Kiteboarding at the Dutch coastline in 2022

Stefanie Smans

Further reading

- Peter Campbell & Stuart Webb: History of kitesurfing.

Airborne wind energy

Makani climate action (2019)

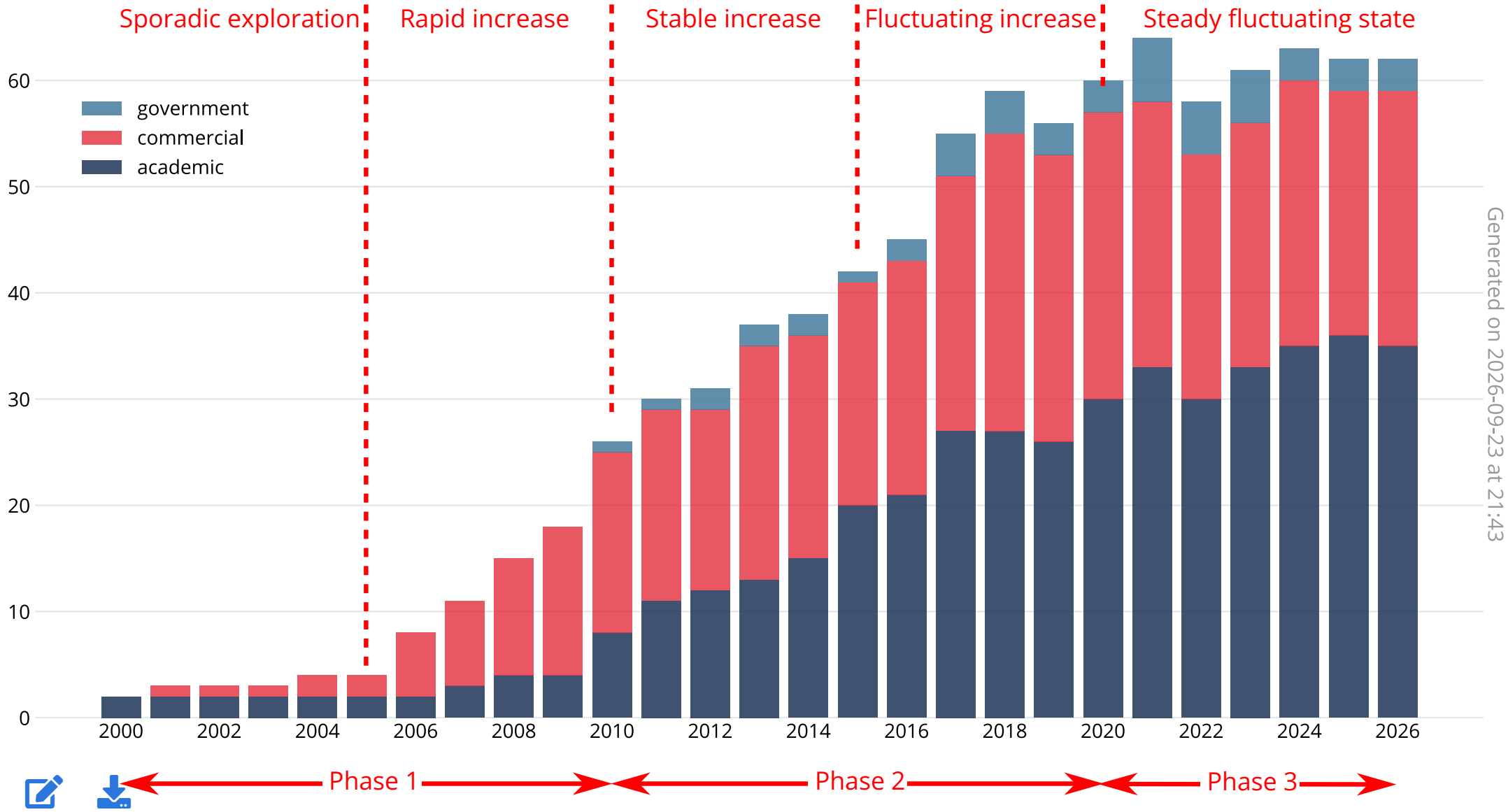


Andrea Dunlap/Makani

Three phases of development

- **2000-2010**: pioneering first phase of renewed interest with isolated R&D and proof of concept demonstrations
- **2010-2020**: second phase of increasingly networked R&D leading to the formation of the industry sector and pre-commercial technology demonstrations
- **Since 2020**: third phase of first pre-commercial deployments in relevant environments

Technology emergence since 2000



Wubbo Ockels



Stanford 2010



Leuven 2011



Berlin 2013



Delft 2015



Freiburg 2017



Glasgow 2019



Milan 2022



Madrid 2024



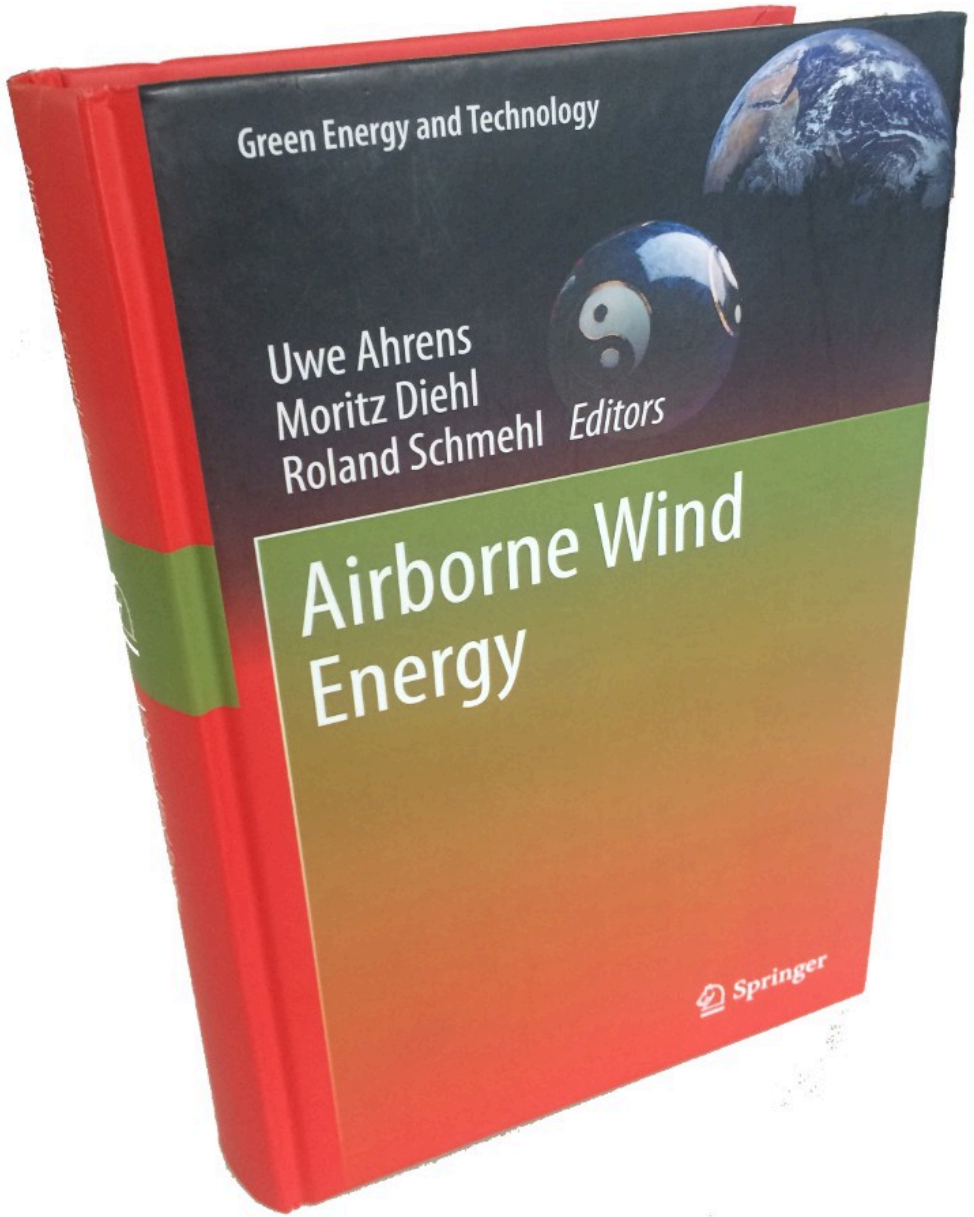
Porto 2026



Textbook 2013

- First textbook on AWE
- Published 2013 with Springer
- 35 peer-reviewed chapters
- 611 pages
- 162k Accesses, 198 Citations as of September 2026

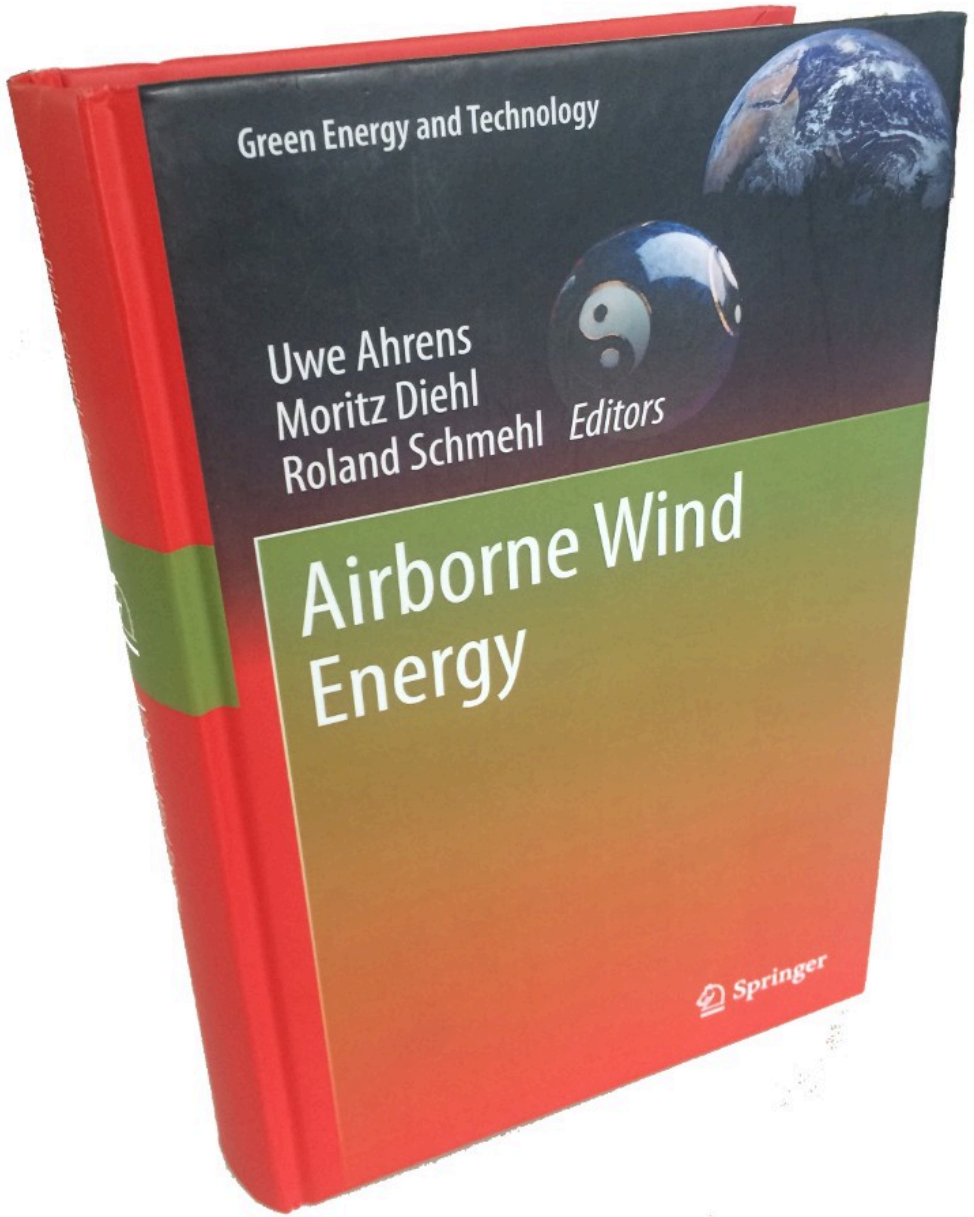
▸ High-impact publication



Textbook 2018

- Second textbook on AWE
- Published 2018 with Springer
- 30 peer-reviewed chapters
- 752 pages
- 74k Accesses, 100 Citations as of September 2026

▸ Second high-impact publication



Journal Special Issue 2023

- **Airborne Wind Energy Systems**
- Edited by Christoph M. Hackl and Roland Schmehl
- Open access journal **Energies**
- 23 contributed articles

iea wind tcp task 48

Second term task structure (2025-)

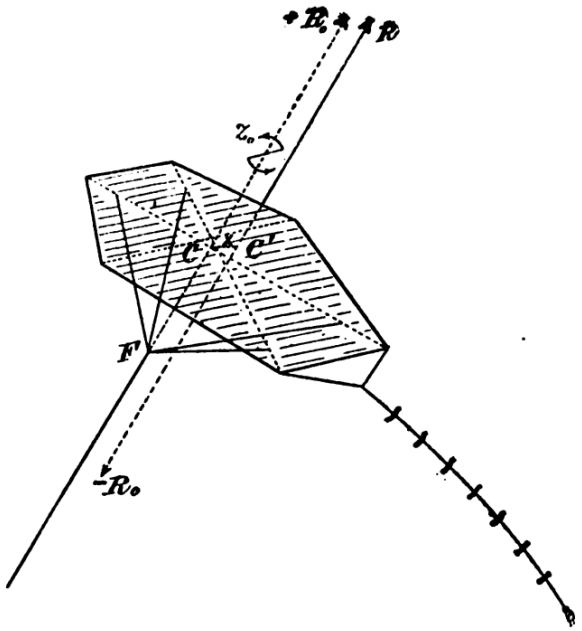
WP0: Task coordination	WP1: Materials, Manufact. & Supply	WP2: Models and tools	WP3: Regulation and deployment	WP4: Social Acceptance
• Organisation & management of Task • Website • Social media • Communication • Dissemination • Exploitation	• Materials & Design • Life-Cycle Analysis • Definition of test strategies for material and critical components • Manufacturing • Supply Chain • Standardization & certification	• Joint reference models • Integrated design and analysis workflo • Design & analysis tools • Control models • Grid integration • Wind resources	• Safe Airspace Integration and regulation • Siting and permitting • Market preparation • Standardization	• Framing, Narratives, • Socio-Political and Institutional Acceptance • Local Acceptance • Participation, Benefit-Sharing, and Co-Creation • Dynamics of Acceptance • Sound Emissions • Environmental Impacts
• Task reporting • Communication outputs	• Component atalogue • LCA • Materail catalogue • Testing standards	• Ref. model workshop • MDAO framework • Power curve simulations • Control ref. Model • Farm-level deliverable • Grid integration model	• Recomd. Practices on airpsace integration & on permitting • Market-entry studies • First approved AWE standards	• Guidelines for design • Synthesis report • Comparative case studies • Repository surveys & envirnomental studies

Kitepower on PostNL Innovation Stamp (2021)



Homework

Study Marvin's seminal work The Mechanics and Equilibrium of Kites from 1896, and explain why he contests the existence of the concept of a **center of pressure** as a distinct point.



References

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Grund, R.: Über eine neue Drachenkonstruktion. In: Assmann, R. and Hergesell, H. (eds.) Die Arbeiten des Preussischen Aeronautischen Observatoriums bei Lindenberg. pp. 1–6. F. Viehweg und Sohn, Braunschweig (1930)

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Oberth, H.: Das Drachenkraftwerk. Uni Verlag, Dr. Roth-Oberth, Feucht, Germany (1977)

Ricker, G.A.: Planes obtain weather data once secured by kites. Journal of the Franklin Institute. 211, 776 (1931). https://doi.org/10.1016/S0016-0032(31)90554-1

Robinson, M.: Meteorological kites - scientific kites of the industrial revolution, http://www.kitehistory.com/Miscellaneous/meteorological_kites.htm

Schmidt, W., Anderson, W.: Kites: Pioneers of atmospheric research. In: Ahrens, U., Diehl, M., and Schmehl, R. (eds.) Airborne wind energy. pp. 95–116. Springer, Berlin Heidelberg (2013)

Webster, G.: Kite for a purpose (the golden age of kites?). In: The kiteflier. pp. 15–25 (2003)

Wellicome, J.F., Wilkinson, S.: Ship propulsive kites - an initial study. University of Southampton, Department of Ship Science (1984)

Questions?



r.schmehl@tudelft.nl