



BALLOONS

History.....	1
Manned balloons	2
Types.....	3
Extensible balloons	3
Equal pressure balloons	3
Hot-air open balloons.....	4
Super-pressure balloons	4
Two-phase balloons	5
Lifting force	5
Weather balloons.....	6
Stratospheric balloons.....	6
Planetary balloons.....	7
References.....	7

A balloon is a flexible bag normally filled with a gas (water-filled balloons are throw-out toys). Balloon, ball, ballot, all come from It. *palla*, inflated, swollen.

Ancient bags were just animal bladders, but they are too heavy for lifting; the first flying balloons were made of paper, up to mid-19th century, were rubber was introduced, and later neoprene (polychloroprene), nylon, polyester (mylar), metallised foil, etc.

The gas most often used to inflate balloons is air, but buoyant balloons (lighter than air) are made of hot air, hydrogen, helium, town gas, natural gas, ammonia..., with helium being the most used. Vacuum is impractical for large sizes (the shell will collapse), and [solid fillings](#) lighter than air are not yet available.

Lifting balloons are lighter-than-air aircraft ([aerostats](#)). When an aerostat has its own propulsion, it is called a dirigible or airship (their shape is no-longer spherical but streamlined, to minimise air resistance).

History

The chronology of balloon applications is representative of other invention purposes:

- Entertainment: decorative, amusement (light ball playing, rocketing), publicity.
- Military: surveillance, defence and war.
- Exploration: the balloon is the oldest and conceptually simplest flying machine.
- Scientific: atmospheric physics (meteorology), chemistry, and biology.
- Technology: communications (a stratospheric antenna may substitute 100 ground cellular antennas).
- Medicine: to reduce the stomach size, to unblock blood vessels near the heart, or to secure catheters.
- Astronomy in the γ -ray, X-ray, UV and IR bands.

- Space experiments: technologies, exobiology, and planetary atmospheres.

First balloon records date from the 2nd century AD in China (for military communications, and hot air was always used until Joseph Black proposed the use of hydrogen (shortly after H. Cavendish analysed it in 1766; hydrogen was known since Paracelsus' time, but only as 'flammable gas' obtained by reaction of metals with acids).

Manned balloons

Motivation for a person to be lifted by a balloon (as for most human endeavours) started for exploration (what is up there, how our world is seen from there), and followed for applications (scientific, military...). It was long time known that air was thinner at high elevation (as reported, for instance, in the 16th century by Spanish physicians exploring the Andes high-lands at 4000 m altitude), and it was also known that, because of Earth's curvature, the higher the observer, the farther we can see. The distance to the horizon, d , from a height h above ground, assuming a perfect spherical Earth of radii R , with no air, is $d = \sqrt{h(2R + h)} \approx 3570\sqrt{h}$, with h and d in [m] (e.g. for a standing person with $h=1.7$ m eye height, $d=4.7$ km; from the 400 km of ISS altitude, $d=2300$ km)..

This first manned free flight took place on 21st November 1783 (the same year that Lavoisier named the gas hydrogen), at Paris, on a hot air balloon built by the Montgolfière brothers (paper-manufacturing entrepreneurs) and piloted by the Physics teacher Pilâtre de Rozier (the first man to fly and the first flight victim), accompanied by F. Laurent, the Marquis de Arlandes who helped Rozier to get the royal favour (Louis XVI wanted to use convicts instead). The 15 m in diameter balloon bag was made of paper, with linen threads to hold a wicker gallery for two passengers and a fire basket with a burner throwing a flame inside to keep the air hot. It reached about 1 km high, covered some 9 km and lasted some 25 minutes. First, the Montgolfière had experimented with unmanned balloons, and after with animals (a sheep, a duck and a hen), and later with people aboard tethered balloons (the first captive flight with humans on board took place on 19 October 1783 with Pilâtre de Rozier, Jean-Baptiste Réveillon and Giroud de Villette, at the Folie Tiron in Paris). Pilâtre de Rozier and his companion, Pierre Romain, died on 15th June 1785 when their balloon crashed near the Pas-de-Calais during an attempt to fly across the English Channel, when trying to open a gas-release valve on top of their combined balloon (a bag of hydrogen on top of a larger bag of hot air, to enhance altitude control).

On 1st December 1783 (ten days later than the first hot-air flight), Sorbonne Prof. J. Charles (together with N. Robert, an artisan that achieved the gas-proof varnished silk envelop) made the first manned flight in a hydrogen-filled balloon from the Champ de Mars in Paris (some 400 000 people attended, almost half of Paris population, including the American ambassador B. Franklin). The large amount of hydrogen used was obtained by mixing iron scrap with sulfuric acid. This flight reached an estimated altitude of about 3 km, covered 20 km and lasted 2 hours, including a short unwanted return to air when Robert jumped off the gondola on the first landing. Charles' balloon was 8 m in diameter, had a neck open at the bottom to equalise pressure (losses by diffusion are minimal), and a commanded valve at the top to let gas escape and allow the balloon to descend; to allow it ascend again, the balloon carried a supply of

sand ballast that could be thrown overboard. Charles took temperature and pressure measurements along the way.

Three months after Charles' flight, another balloon pioneer, Jean-Pierre [Blanchard](#), made his first flight and later went on demonstrating flights all through European capitals. He also demonstrated with animals the use of the parachute (invented in 1783 by Sébastien [Lenormand](#)), and later profited himself when in 1793 his hot air balloon ruptured and he used a parachute to escape.

Hydrogen and helium balloons have important leakage through the wall (they lose their buoyancy in a few days, unless specially coated). The rubber balloon was developed by Faraday in 1824, but latex was sticky and unreliable until Goodyear vulcanisation in 1839 (mass production only started a century later).

High-altitude balloon manned flight gave rise to aerospace medicine: in 1875, near Paris, meteorologist Gaston [Tissandier](#) and two companions, a journalist and a naval officer, were able to reach in a balloon the unheard-of altitude of 8600 m but only Tissandier survived (but became deaf). In 1883, Tissandier fit a Siemens electric motor to an airship, thus creating the first electric-powered flight. The first dirigible (a steerable balloon powered by a steam engine) was attempted by Henri Giffard in 1852.

Fire risk has always been one of the main concerns on flying balloons and dirigibles, not only on those lifted by a flammable gas, but on hot air balloons (on the first flight, Rozier carried a sponge and a bucket of water to extinguish stray fire-sparks. The burn out of the Hindenburg in 1937, with 35 deaths, was the major tragedy).

Types

Balloons may be classified into the following categories: extensible, super-pressurized, equal pressure, phase-change, and hot air (and their combinations).

Extensible balloons

This is the most used, from playthings to weather sounding. They are made of rubber and inflated with a given mass of light gas, sealed, and allowed to rise until it bursts. At no altitude is it in buoyant equilibrium, since the lifting force, assuming same pressure, temperature, and volume, is constant $F_{\text{lift}} = (m_t - m_g)g = m_g(M_v/M_g - 1)g$. See 'Weather balloons' for further details.

Equal pressure balloons

In the equal pressure (or zero pressure) balloon, an extensible inelastic bag is used, with the internal pressure never exceeding environmental pressure. It is only partly inflated before it is launched, rises until the gas inside expands to fill the balloon's fixed volume, and then a valve is left permanently open to maintain the internal pressure equal to the atmospheric pressure. The balloon rises to an equilibrium floating altitude, maintained by venting gas if the internal temperature increases, and by dropping ballast if the temperature decreases. Equilibrium at altitude z is such that $m_t g = \rho_e V g$; e.g. at $z = 40$ km, environmental density is $\rho_e = 0.0038 \text{ kg/m}^3$, so that the biggest balloons ($V > 10^6 \text{ m}^3$) can lift $m_t = 3800 \text{ kg}$ of total mass (payload + envelop + ballast). The bag is made of 10..20 μm low density polyethylene (LDPE).

Balloons

Hot-air open balloons

Also known as montgolfiers, they rely for lift entirely on the temperature differential between the atmospheric gas inside the balloon and the air outside. The air inside a non extensible bag is heated and thus made less dense than the air at the same pressure outside. The balloon rises and floats at the altitude where it is neutrally buoyant. In the case of a solar heated machine, the temperature differential is due to a strong absorption coefficient of the fabric in the visible coupled with a small emissivity in the infrared.

Infrared Montgolfière's balloons have been used for Arctic stratospheric research. These balloons are 40 meters in diameter, and have an aluminized mylar outer top shell along with a transparent polyethylene bottom shell. The bottom shell is designed to absorb infrared radiation from the ground and clouds during the night, allowing it to stay afloat without having to dump ballast. The hot air balloon is far less efficient than the buoyant gas balloon because the difference between the densities of the gas inside and outside is very small; therefore its volume must be much larger in order to carry the same payload. The larger size increases storage and inflation problems.

A Rozière balloon is a double balloon system containing one gas balloon and one Montgolfière.

Super-pressure balloons

This is made of non-extensible fabric, and is designed to float stably with an internal pressure greater than that of the ambient atmosphere. It is only partly inflated before it is launched, rises until the gas inside expands to fill the balloon's fixed volume, and soon afterward reaches an equilibrium altitude. From there on, it will stay at a constant density level, moving nearly horizontally with the wind. During the day, the temperature of the buoyant gas increases with the solar heating and reaches a maximum. It is essential that the fabric strength withstands the maximum corresponding pressure. At sundown, the buoyant gas temperature drops rapidly, and the internal pressure varies directly with the temperature, eventually reaching a minimum.

For the balloons to stay aloft, the minimum internal pressure has to be superior to the local atmospheric pressure. If the skin's material is strong enough to resist the super-pressure during day-time, the lifetime is limited by the leak rate of the buoyant gas. Because the skin tension per unit area increases with the radius of curvature, the balloon's diameter is limited to a 10 m (equal pressure balloons reach $D > 100$ m). Being small, the balloon can only carry a very limited payload in addition to its own mass. The thickness of the skin, some 50 μm , imposed by the strength needed to withstand the maximum overpressure, therefore sets an ultimate maximum to the mass of the payload. May be made of mylar or mylar-polyethylene sandwiches; mylar is strong (tensile strength $\sigma = 140$ MPa) but presents highly stressed points and holes, and polyethylene is not strong enough for super-pressurized balloons ($\sigma = 4$ MPa). They burst for $\Delta p \approx 800$ hPa with a 2% yield.

Mylar is a biaxially-oriented polyethylene terephthalate (boPET), a thermoplastic polymer resin of the polyester family, developed in the mid-1950s by DuPont and ICI. In 1960 and 1964, NASA launched the Echo satellites, 30 m diameter balloons, made of metallized 0.13 mm) thick boPET film.

Two-phase balloons

The two-phase or reversible balloon contains a fluid in liquid-vapour equilibrium at the temperature range where the balloon operates. Above the temperature of condensation, the fluid vaporises and provides buoyancy (the remaining liquid below acts as an inert mass). The altitude of the balloon will oscillate around the altitude of the condensation point if the temperature of the atmosphere decreases with altitude. The system can be optimized by the presence of another, non condensable gas which will provide buoyancy all the time.

Lifting force

Balloons are nearly spherical to minimise area, but the pumpkin shape has better structural properties, and elongated (pear-shape or quasi-cylindrical) are common. Horizontal motion is just by drag entrainment, although attached kites are investigated for control.

Balloon vertical motion is dictated by momentum equation:

$$\frac{d(m_T \dot{z})}{dt} = F_{Arch} - F_{weight} - F_{drag} = \rho_e V g - m_T g - c_D \frac{1}{2} \rho_e \dot{z}^2 A_{\perp} = \underbrace{(\rho_e - \rho_g) V g}_{F_{lift}} - \underbrace{m_s g - c_D \frac{1}{2} \rho_e \dot{z}^2 A_{\perp}}_{-F_{resist}}$$

where m_T is total mass (total=solid+(liquid if any)+gas; solid=envelop+ballast+payload), and e=environment, g=gas inside, $V_g=V$ assumed. Balloon acceleration can be neglected most of the times.

When there are no forces applied (not even weight), total momentum is conserved, but one may still have jet propulsion, $m_1 \dot{z}_1 = -m_2 \dot{z}_2$. Even with $F_{Arch}=0$ the balloon may ascend, with $m_1 \ddot{z} = -\dot{m}_2 \dot{z} - F_{weight}$, as in rocket balloons.

The lifting force results from the difference in density between the environment ('e', the Archimedean upward force), and the gas inside ('g', the gas weight, leaving aside all other weights), $\rho_e - \rho_g > 0$, which can be achieved by:

- Having vacuum ($\rho_g=0$), or at least low pressure, inside. It is not practical for structural reasons.
- Having a lighter gas, $M_g < M_e$ ($M_e=29$ g/mol, $M_{N_2}=28$ g/mol, $M_{CO}=28$ g/mol, $M_{C_2H_2}=26$ g/mol, $M_{Ne}=20$ g/mol, $M_{NH_3}=17$ g/mol, $M_{CH_4}=16$ g/mol, $M_{H_2+CO}=15$ g/mol, $M_{He}=4$ g/mol, $M_{He_3}=3$ g/mol, $M_{H_2}=2$ g/mol). The best cost-effective is H_2 , but it is flammable and helium is preferred. The lifting force at room conditions, $F_{lift}/V=(\rho_e - \rho_g)g$ is around 10 N/m³ for He or H_2 (i.e. 1 m³ of room air can lift around 1 kg); the lifting force decreases with altitude as air-density does, what is compensated by increasing the balloon volume. The gas inside may be kept tight (closed envelop) or at zero-pressure-difference with the environment (openings at the bottom). Charles flight in 1783-11-30 was with the hydrogen-filled balloon opened at the bottom. To first approximation:
 - Equilibrium requires a matching of lift and weight (neutral buoyancy):

$$0 = F_{Archim} - F_{weight} = \rho_e V g - m_{tot} g = (\rho_e - \rho_g) V g - m_{sol} g \xrightarrow{\text{if } \rho_g \ll \rho_e} m_{lifted} = \rho_e V$$

- Stability at the equilibrium height, z_0 , further requires a return after disturbances, such that $m\ddot{z} = -\omega^2 m(z - z_0) - \gamma \dot{z}$ with $\omega = 2\pi/T$ is the angular frequency (T being the period of the oscillations around z_0), and γ the damping coefficient.
- Having the same gas at lower density by keeping it hot (since lowering the pressure is against structural integrity). Rozière's (first manned) flight in 1783-11-21, on Montgolfière's balloon was hot-air lifted. One may feed the balloon with hot air and kept it hot by a flame underneath, or the air may be heated by solar radiation and infrared radiation from the surface and the atmosphere.
 - Equilibrium requires:

$$0 = F_{lift} - m_s g = (\rho_e - \rho_g) V g - m_s g = \left(\frac{p_e M_e}{R_u T_e} - \frac{p_g M_g}{R_u T_g} \right) V g - m_s g = \rho_e \left(1 - \frac{T_e}{T_g} \right) V g - m_s g$$
 - Stability further requires a return after disturbances.

Weather balloons

Although meteorological satellites have taken over most of the weather research and forecast activities, the precise vertical analysis of variables at a point still relies on sounding balloons, since its massive implementation in 1958, which are released at nearly 1000 weather station trough the world at least two times a day (00 UTC and 12 UTC). Table 1 gives some typical balloon characteristics (the small ones, with no payload, are used as visual clues to measure cloud altitude).

Table 1. Typical weather-balloon performance*.

Total mass [g]	10	30	100	200	350	600	1000	1500	3000
Initial diameter [cm]	30	50	90	120	130	140	160	180	210
Typical payload [g]	0	0	0	250	250	250	250	1000	1000
Free-lift [g]	5	60	300	500	600	900	1100	1300	1700
Ascent rate (m/min)	60	150	250	300	300	300	300	300	300
Maximum height (km)	12	13	30	21	26	31	34	34	38

*WMO Guide to Meteorological Instruments and Methods of Observation, 2006.

Stratospheric balloons

Balloons are presently the only long-time carriers in the 20 km to 50 km altitude range (the record in 2002 was 53 km, reached with a 60 000 m³ helium-filled balloon made of 3.5 μm thin polyethylene film). Aircraft can be used below 20 km, and orbiting spacecraft above 200 km altitude, but only rockets can presently visit the layer between 50 km and 200 km, and only on the flight.

The balloon is made of rubber, natural (latex) or artificial (neoprene) and filled with helium (or hydrogen). Depending on size, the shape before release from ground may be a near-spherical soft body, or a long crumpled parachute-like body. Aloft, all are nearly spherical or pear-shaped, with diameters that may reach 100 m in the largest scientific balloons. The payload may range from a small electronics box (with sensors, signal processor, transmitter and batteries), up to 4000 kg in the largest case, hanging from a long thread some 30 m long, at the top of which, near the balloon attachment, there is a parachute to procure a safe landing of the payload.

Applications of these balloons may be for stratospheric research, for space tests (at 50 km altitude there is only 0.1 % of the atmosphere mass above), for military or civil communications & surveillance; e.g. the radar range from a 30 m tower is 20 km on low-flight, whereas from 25 km it is 500 km; a station-keeping aircraft (usually a solar-powered airship) might provide wide-band wireless Internet connection. The most promising altitude for the latter is around $z=20$ km, where [stratospheric winds](#) are at their minimum all year around (between 5 m/s and 25 m/s in middle latitudes).

Planetary balloons

Planetary balloons, sometimes called aerobots (for aerostatic robots), can be deployed on planets and moons with an atmosphere, like Venus, Mars, or Saturn's moon Titan.. In 1985 the Soviet Venus probes Vega 1 and Vega 2 each dropped a balloon radiosonde into the atmosphere of Venus; one of them was tracked for two days, travelling 13 000 km at around 55 km height.

One of the trickier aspects of planetary balloon operations is inserting them into operation. Typically, the balloon enters the planetary atmosphere in an "aeroshell", a heat shield in the shape of a flattened cone. After atmospheric entry, a parachute will extract the balloon assembly from the aeroshell, which falls away. The balloon assembly then deploys and inflates.

In the hydrogen atmospheres of giant planets, only hot-air type balloons, using environmental hydrogen, of course, would provide lift.

References

- <http://www.vectorsite.net/avbloon.html>
- <http://en.wikipedia.org/wiki/Balloon>
- <http://mars.jpl.nasa.gov/technology/balloons/>
- Müller, I. and Strehlow, P., "Rubber and Rubber Balloons: Paradigms of Thermodynamics", Springer-Verlag, 2004.

([Back to Index](#))