Ascent in a balloon

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More than a century before the first airplane flights, in fact as long ago as the 1780s, the first manned balloon flights were made. The Montgolfier brothers Joseph and Étienne developed the first practical hot-air balloons and their names were almost as well-known as Armstrong and Aldrin are in our day, although it wasn’t the brothers who first flew in an untethered flight in one of their own balloons. (The commemorative image on the right shows them idolized in very French style. The brothers were allegedly forbidden to fly in their contraption by their father!) As with the space-race, animals were first sent up (a sheep, a duck and a cockerel) in September 1783 and about two months later the first aeronauts, Pilâtre de Rozier and the Marquis d’Arlandes, braved the unknown in a circular gallery at the base of their balloon. Montgolfier’s hot-air balloons didn’t have the on-board burners that you’ll see on every balloon these days. These burners were a 20th century development. They did have a flying fire but it wasn’t that effective and as a result, the first hot-air balloons didn’t rise very high or travel very far before the hot air cooled and the balloon sank to the ground.

At the very same time, though, nearby in Paris Jacques Charles was developing the hydrogen balloon, the hydrogen being produced by adding sulphuric acid to iron filings. Hydrogen kept its lifting power with height much better than cooling hot air. In December 1783, less than two weeks after the first manned flight in a hot air balloon, Charles and a companion (or two) launched their hydrogen-filled balloon from the Jardins des Tuileries. They traveled higher and further than any Montgolfier balloon had done. Charles appreciated that ballooning provided spectacle, adventurous travel and an opportunity to explore the atmosphere. The volume of the balloon was crucial to its lifting power and in his own laboratory Charles investigated the relationship between the volume of a gas and its temperature and arrived at the fundamental expression known as “Charles’ Law”, still quoted in physical science textbooks and incorporated into the “Ideal Gas Law” (PV = NRT in standard symbols). In effect the ideal gas law is a combination of Charles’ Law and Boyle’s Law.
Hydrogen balloons became the balloons of choice for the next century and a half. What must it have been like to travel in a hydrogen balloon before the days of aircraft? The words of the Frenchman J. H. Fabre written in the 1860s may whet your curiosity. It must be a great moment for the balloonist when the last rope holding the balloon is let go. The aerial machine oscillates throughout its swollen bulk; it is set in motion and starts on its journey. A stone sinks less swiftly into the abysses of the ocean than the balloon rises into the heights of the atmosphere. In a few seconds the crowd of onlookers is like an insignificant lot of ants; houses look ridiculously small, and the town appears like a little heap of white cubes which could easily be held in the hollow of the hand. Here comes a cloud. The balloonist plunges into it and everything vanishes. Another rush, and the balloon emerges from the grey depths of the cloud like a marine monster coming to breathe on the surface of the water. It rises into the higher levels, which are always serene and bathed in sunlight. It reaches a height of ten thousand metres, the greatest height to which mankind has ever penetrated. At intervals the balloonist sees the earth through holes in the clouds, but it appears vague on account of its distance, and terrifying by its depths. A dozen ropes and a wicker basket hold him suspended over the abyss: what would happen to him if the frail craft were to be ship-wrecked and thrown from a height of ten thousand metres? Our hair rises on end if we only think of such a fall. In three-quarters of a minute the unfortunate man would touch the ground at a speed of 441 metres per second, which is nearly the speed of a cannon-ball; and after the shock he would have lost his human form and would be unrecognizable. We divert our eyes from the horrible spectacle. Yes, quite.

One of the early professional aeronauts was Henry Coxwell, who had a balloon factory in Sussex. Coxwell made hundreds of ascents. In the 1860s several of these were with James Glaisher, a pioneering meteorologist, and in 1862 they held the world record for the height reached (over 10 km), a record that almost cost Glaisher his life, for the lack of oxygen and cold that must have been close to -50° C had rendered him unconscious and Coxwell almost paralyzed. Glaisher’s balloon ascents focused meteorologists’ attention on the vertical structure of the atmosphere, which as we now know is very important in determining the weather. In one sense it all started in Aberdeen, at the 1859 meeting of the British Association for the Advancement of Science, which voted to form a committee for the
exploration of the upper atmosphere by balloon. Glaisher’s ascents were the result of this initiative.

The following account describes a trip with Henry Coxwell in a hydrogen-filled balloon. Don your padded clothes, collect your barometer, thermometer and dew-point hygrometer, throw in a small telescope for fun and prepare for some serious oxygen starvation at altitude as you step over into the wicker basket resting on the grass beneath Coxwell’s balloon.

*Imagine, then, the balloon somewhat more than half inflated, eager for flight, with only one link connecting it with the earth, viz., a rope attached to an instrument called a liberating iron or catch.*

*All the ballast, instruments, and everything else placed in the car, with the grapnel attached outside, so as to be readily detached, and these amount to four thousand pounds. The balloon brought to a nice and even balance, so that the addition of twenty pounds would prevent it from rising, and its removal then would give it the required ascending power.*

*All, then, is ready. Mr. Coxwell, with his hand upon the catch, looks up at the sky, and is, apparently, staring at vacancy; but he is not. If the sky be partially cloudy, he watches till he is midway between the cloud that has passed and that which is coming, so that he may have a clear sky, and at least see the earth beneath, and avoid, if possible, passing through a cloud; for the cloud which preceded will always precede, and that which follows will always follow. Nor is that all; if he can start in a calm, he avoids much rotatory motion.*
The favourable moment arrives; the catch is pulled, and we are free, but not only so, we are in profound repose; no matter how violent soever the wind may be, no matter how agitated the balloon may have been swaying to and fro, now on this side, now on that, with sudden and violent action, notwithstanding all the efforts of the many individuals who were struggling to hold it; all agitation in a moment ceases, and we are in perfect stillness, without any sense of motion whatever, and this continues throughout our entire flight.

Once away, we are both immediately at work; we have but little time for graceful acknowledgments to cheering friends. Mr. Coxwell proceeds to put the car in order, and accordingly looks to it, to his balloon, and to the course we are taking; and I must get my instruments in order. Without delay, therefore, I at once place them in their situations, adjust them, and take a reading as soon as possible. In a few minutes we are from one to two thousand feet high; Mr. Coxwell looks intently upwards, to see how the huge folds of the balloon fill into the netting.

If we have started from a town, its busy hum attracts our attention, and a glance shows us the many upturned faces in every street, and the town itself, which looks like an engineer's model in motion; and the now fast fading cheers of our assembled friends next attract our attention, and another glance shows us the quickly-diminishing forms of the objects we so recently left.

On approaching the clouds, Mr. Coxwell recommends me to take a farewell peep at the earth; and as I do this, the clouds receive us, at first in a light gauze of vapour, and then in their chilly embrace, where I examine their structure, and note the temperature of the dew-point particularly.

Shortly it becomes lighter, the light gradually increasing, till it is succeeded by a flood of light, at first striking, then dazzling; and we pass out of a dense cloud, to where the clouds open out in bold and fantastic shapes, showing us light and shade and spectral
scenes, embellished with prismatic colours, disporting themselves around us in wild
grandeur, till at length we break out into brilliant sunshine, and the clouds stretch away
into a perfect sea of vapour, obscuring the earth entirely; then in the line from the sun
passing us, we see the shadow of the balloon and car and ourselves upon the clouds,
very large and distinct, with encircling ovals of rainbow tints; forming altogether a
wonderful scene - a wonderful contrast to that of their lower surface.

When approaching the height of three miles, Mr. Coxwell directs my attention to the fact
that the balloon is full, and the gas is issuing from the safety-valve. He then directs my
attention to the fit and proportions of the netting. I find the gas, which was before cloudy
and opaque, is clear and transparent, so that I can look right up the balloon, and see the
meshes of the network showing through it; the upper valve, with its springs and line,
reaching to the car, and the geometrical form of the balloon itself. Nor is this an idle
examination.

In passing through the cloud the netting would gather moisture, augmenting the weight
of the balloon; if this should not all have evaporated, the network would have become
frozen, and be as wire-rope; so that, it the diamond shape of the netting when under
tension, and the form of the crown of the balloon, be not symmetrical, the weight might
not be equally distributed, and there would be danger of it cutting the balloon. A sense
of security, therefore, follows such an examination.

We are now three miles high. A stream of gas continually issues from the neck, which is
very capacious, being fully two square feet in area, and which is always left open; and
after a time I see Mr. Coxwell, whose eye has been continually watching the balloon,
pass his fingers over the valve line, as if in readiness to pull the cord. I look inquiringly
at him. He says, “The tension on the balloon is not greater than it would bear in a
warm stratum of air with safety; but with a chilled balloon it is better to allow some
escape at the top, as well as a good deal from the bottom.”

We are now four miles high, and far beyond the reach of all ordinary sounds from the
earth. A sea of clouds is below us, so dense that it is difficult to persuade ourselves
that we have passed through them. Up to this time, little or no inconvenience is met with;
but on passing now, much personal discomfort is experienced; respiration
becomes difficult; the beating of the heart at times is audible; the hands and lips
become blue, and at higher elevations the face also; and it requires the exercise of a
strong will to make and record observations.
At five miles high, Mr. Coxwell counts the number of his sandbags, and calculates how much higher we can go, with respect to the reserve of ballast necessary to regulate the descent.

Then I feel a vibration through the car, and, on turning round, see Mr. Coxwell in the act of lowering the grapnel; then looking up at the balloon; then scanning the horizon, and weighing apparently in his mind some distant clouds, through which we are likely to pass in going down.

A glance suffices to show that his mind is made up how much higher it is prudent to rise, and how much ballast it is expedient to preserve.

We are six miles high, and now the balloon lingers, as it were, under the deep blue vault of space, hesitating whether to mount higher, or begin its descent without further warning. We now hold consultation, and then look around, giving silent scope to those emotions of the soul which are naturally called forth by such a widespread range of creation.

Our course is now about to change, but here I interpose with “No, no; stop; not yet; let us remain so long, that the instruments are certain to take up their true readings, so that no doubt can rest upon the observations here. When I am satisfied, I will say, ‘Pull’”.

Then we reach the highest point; here we respire with difficulty, and talk but little. In the centre of this immense space; in solitude, without a single object to interrupt the horizon view for two hundred miles or more in every direction; abstracted from the earth; upheld by an invisible medium; a white sea below us; so far below, we see few, if any, irregularities. I watch the instruments, but forcibly impelled again, look round from the centre of this immense vacuity, whose bounding line is fifteen hundred miles, including an area of a hundred and thirty thousand square miles.

When I find no further changes are proceeding, I wave my hand and say, “Pull”.

A deep resonant sound is heard overhead; a second pull is followed by a second report that rings as with shrill accompaniment down the very sides of the balloon. It is the working of the valve which causes a loud booming noise, as from a sounding-board, as the springs force the shutters back. In that solitary region, amid a silence so profound that no silence on earth is equal to it, this sound strikes one forcibly.

It is, however, one sound only; there is no reverberation, no reflection; and this is characteristic of all sounds in the balloon, one clear sound, gone in a moment. No sound ever reaches the ear a second time. But though the sound from the closing of the valve in those silent regions is striking, it is also cheering, it is reassuring, it proves that the balloon is right.

We have descended a mile or more, and our feelings improve with the increase of air and warmth. But silence reigns supreme. Mr. Coxwell turns his back upon me, scanning the distant cloudscape, speculating as to when and where we shall break through, and catch sight of the earth.
On nearing the clouds we observe the counterpart of our own balloon reflected upon them, at first small in size, momentarily increasing. This spectral balloon is charming to look upon, and presents itself under a variety of aspects, which are magnified or diminished by the relative distance of our balloon from the clouds, and by its position in relation to the sun, which produces the shadow.

At mid-day, it is steep down, almost underneath; but it is more grandly defined towards evening, when the golden and ruby tints of the declining sun impart a gorgeous colouring to cloud-land. You may then see the spectre balloon magnified upon the distant cloud-tops, surrounded with three beautiful circles of rainbow tints. Language fails utterly to describe these illuminated photographs, which spring up with matchless truthfulness and choice decoration.

Just before we enter the clouds, Mr. Coxwell having made all preparations for the descent, strictly enjoins me to be ready to put up the instruments, lest, when we lose the powerful rays of the sun, and absorb the moisture of the lower clouds, we should approach the earth with too great rapidity.

In passing from bright sunshine into cloud, the gas becomes contracted by loss of heat, and the balloon every instant absorbs moisture and so increases its load; both causes combining to make the balloon descend with great rapidity.

We now near the confines of the clouds, see the spectral balloon approaching us, nearly as large as our own, and just then dip swiftly into the thickest of them. We experience a decided chill, and hear the rustling of the collapsing balloon, which is now but one-third full; but cannot see it, so dense is the mass of vapour; one, two, three, four, or more minutes pass, and we are still in the cloud; how thick it must be, considering the rapidity of the descent!

Presently we pass below, and the earth is visible. There is a high road intersecting green pastures; a piece of water like polished steel. An open country lies before us; a shout comes up and announces that we are seen, and all goes well, save the rapidity of the descent, caused by the thick clouds through which we have just passed shutting us out from the sun's rays, and loading us with moisture. Mr. Coxwell counteracts this by means of the ballast, and streams out one bag, which appears to fly up instead of falling down; now another, and still another, but still it goes up, till the wayward balloon is reduced within the bounds of moderation. Mr. Coxwell exultingly exclaims, “I have it now under perfect control, with sand enough, and to spare.”

Glad to find the balloon checked, with the prospect of an easy descent, I read the several instruments as quickly as I can, noticing at the same time the landscape below,
Charming in its constant variation, rich with its mounds of green foliage, fields of various shades of green, intersected by roads, rivers, rivulets, &c.; and all this is seen with a distinctness superior to that on the earth; the line of sight is through a purer and less dense medium, everything seems clearer, though smaller. At the height of four miles over Birmingham, both Mr. Coxwell and I distinguished readily the New Street station, and the several streets in the town, with the naked eye.

After descending slowly for a little time, Mr. Coxwell selects a spot for our descent distant then two or three miles. The current near the earth, which is often stronger than the upper, wafts us merrily in that direction. We are but a few hundred feet from the earth, when Mr. Coxwell requests me to put up the instruments, and he will keep on that level till I am ready. He throws out a little more sand, and I pack up the instruments in their wadded cases. Mr. Coxwell's eye is on the balloon, noting carefully the course it is taking with respect to the inclination of its descent on the spot where he has chosen to land. Shortly he calls out, “Are you all right?”

“All right!” I respond.

“Look out, then, and hold fast by the ropes, we'll stop in the large meadow, with the hedge-row in front.”

Sure enough the grapnel catches in the hedge, and, once again we are connected with the earth by one link. The valve line is drawn, and a little gas is allowed to escape.

The sheep, which have been watching the descending balloon, huddle together, and the cattle wildly scamper in all directions. Villagers break through the hedges on all sides, and we are soon surrounded by an agricultural crowd, some of whom take hold of the rope attached to the grapnel, and, as directed, pull us down, or hold it whilst we float to the centre of a field.

The valve is again opened, gas is allowed to escape by degrees, nothing is allowed to be touched till the reduced buoyancy of the balloon permits the removal of the instruments. The car is gradually lightened, till finally we step out, once more on the earth.

The account above has air-brushed out some of the genuinely dangerous reality of a high ascent. Most climbers need altitude acclimatization if they go above 20,000 feet (6000 m). 6 miles high is 31,600 feet or about 9650 m, higher than Mount Everest. Almost everyone at this height needs additional oxygen. Glaisher didn’t have it and he and Coxwell weren’t much short of perishing, as I’ll relate. In 1875 Gaston Tissandier, a balloon enthusiast and popular writer on science, made a comparable ascent from Paris with two companions in their balloon Zenith. In spite of having some supplementary
oxygen, Tissandier fainted when the balloon reached about 8200 m. When he came to some half-hour later the balloon was sinking fast and one of his companions was shaking his arm and saying ‘throw out some ballast’. This they did and the balloon then rose again rapidly. Tissandier relaxed into a stupor for a second time and according to accounts it is likely the balloon rose to about 8500 m before descending apace. When Tissandier regained consciousness, the balloon was oscillating wildly, descending very quickly and his two companions were crouched in the bottom of the basket with black faces and bloody mouths. The balloon crashed landed and his companions were found to be dead from asphyxiation, lack of oxygen in other words.

I’ll return finally to Glaisher and Coxwell’s record-breaking ascent from Wolverhampton in September 1862. In less than an hour they reached an altitude of 5 miles (8000 m), exceeding the greatest height previously reached. Here is some of what really happened, in Glaisher’s own words. Up to this time I had taken observations with comfort and experienced no difficulty in breathing, whilst Mr Coxwell, in consequence of the exertion he had to make, had breathed with difficulty for some time. Having discharged sand, we ascended still higher; the aspirator [for measuring air temperature] became troublesome to work, and I also found a difficulty in seeing clearly. . . . About 1 hour 52 minutes, or later, I read the dry-bulb thermometer as minus 5º [Fahrenheit]; after this I could not see the column of mercury in the wet-bulb thermometer, nor the hands of the watch, nor the fine divisions of any instrument. I asked Mr. Coxwell to help me to read the instruments. In consequence, however, of the rotatory motion of the balloon, which had continued without ceasing since leaving the earth, the valve-line had become entangled, and he had to leave the car and mount into the ring to readjust it. I then looked at the barometer, and found its reading to be 9¾ inches, still decreasing fast, and implying a height exceeding 29,000 feet.

Shortly after, I laid my arm upon the table, possessed of its full vigour, but on being desirous of using it, I found it powerless . . . . Trying to move the other arm, I found it powerless also. Then I tried to shake myself and succeeded, but I seemed to have no limbs. . . . I dimly saw Mr. Coxwell, and endeavoured to speak, but could not. In an instant intense darkness overcame me, so that the optic nerve lost power suddenly, but I was still conscious, with as active a brain as at the present moment whilst writing this. I thought I had been seized with asphyxia, and believed I should experience nothing more, as death would come unless we speedily descended; other thoughts were entering my mind, when I suddenly became unconscious. . . . I cannot tell anything of the sense of hearing, as no sound reaches the air to break the perfect stillness and silence of the regions between six and seven miles above the earth. My last observation was made at 1 hour 54 minutes, above 29,000 feet . . . . Whilst powerless I heard the words, 'temperature' and 'observation,' and I knew Mr. Coxwell was in the car speaking to and endeavouring to rouse me. . . . I then heard him speak more emphatically, but could not see, speak, or move. I heard him again say, 'Do try; now do!' Then the instruments became dimly visible, then Mr. Coxwell, and very shortly I saw clearly. . . . Mr. Coxwell told me that while in the ring he felt it piercingly cold, that hoarfrost was all round the neck of the balloon, and that on attempting to leave the ring he found his hands frozen. He had, therefore, to place his arms on the ring and drop down. . . . He wished to approach me, but could not; and when he felt insensibility coming over him too, he became anxious to open the valve. But in consequence of having lost the use of his hands he could not do this; ultimately he succeeded, by seizing the cord with his teeth, and dipping his head two or three times, until the balloon took a decided turn downwards. No inconvenience followed my insensibility; and when we dropped, it was in a country where
no conveyance of any kind could be obtained, so I had to walk between seven and eight miles. . . . I have already said that my last observation was made at a height of 29,000 feet; at this time (1 hour 54 min.) we were ascending at the rate of 1000 feet per minute; and when I resumed observations we were descending at the rate of 2000 feet per minute. These two positions must be connected, taking into account the interval of time between, viz. 13 minutes, and on these considerations the balloon must have attained the altitude of 36,000 or 37,000 feet. Again, a very delicate minimum thermometer read minus 11.9º, and this would give a height of 37,000 feet. Mr. Coxwell, on coming from the ring, noticed that the centre of the aneroid barometer, its blue hand, and a rope attached to the car were all in the same straight line, and this gave a reading of seven inches and leads to the same result. Therefore, these independent means all lead to about the same elevation, viz. fully seven miles.

There is no doubt that these guys were tough cookies. To have survived without supplementary oxygen when the air pressure was only 7 inches (~180 mm) compared with normal atmospheric pressure of 760 mm is remarkable. You or I would most likely have ended as Tissandier’s companions did. The cold was almost certainly more intense than Glaisher recorded, for it was found that ordinary mercury thermometers even when swung below the basket received significant heat from the balloon itself, the basket and its occupants and couldn’t respond quickly to the temperature of thin air. The rapid rates of rise and fall of balloons made this issue worse. Because a balloon travels with the surrounding air, there is little natural ventilation in the basket. Glaisher had a thermometer that was aspirated by bellows but abandoned it as unworkable in the circumstances. The problem wasn’t really solved until the end of the 19th century when Assmann invented a reliable aspirating thermometer in which the holder both shielded the thermometer from its surroundings and pushed air past with a clockwork operated fan. It’s just visible at the end of the boom arm on the right of this late 19th century print. The University has an example in its historic scientific instrument collection.

Meteorologist still make atmospheric soundings with balloons but they are all un-manned, telemetering their readings to the ground. Surviving in conditions that are outside our comfort zone is a serious problem, as balloonists found in the 19th century and as those exploring ‘space’ have been tackling ever since the 1960s.

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