The Pall Mall Magazine — The Sensations and Emotions of Aerial Navigation

Alberto Santos-Dumont

The housetops look so dangerous.

Photo by Gallard.

THE SENSATIONS AND EMOTIONS OF AERIAL NAVIGATION.

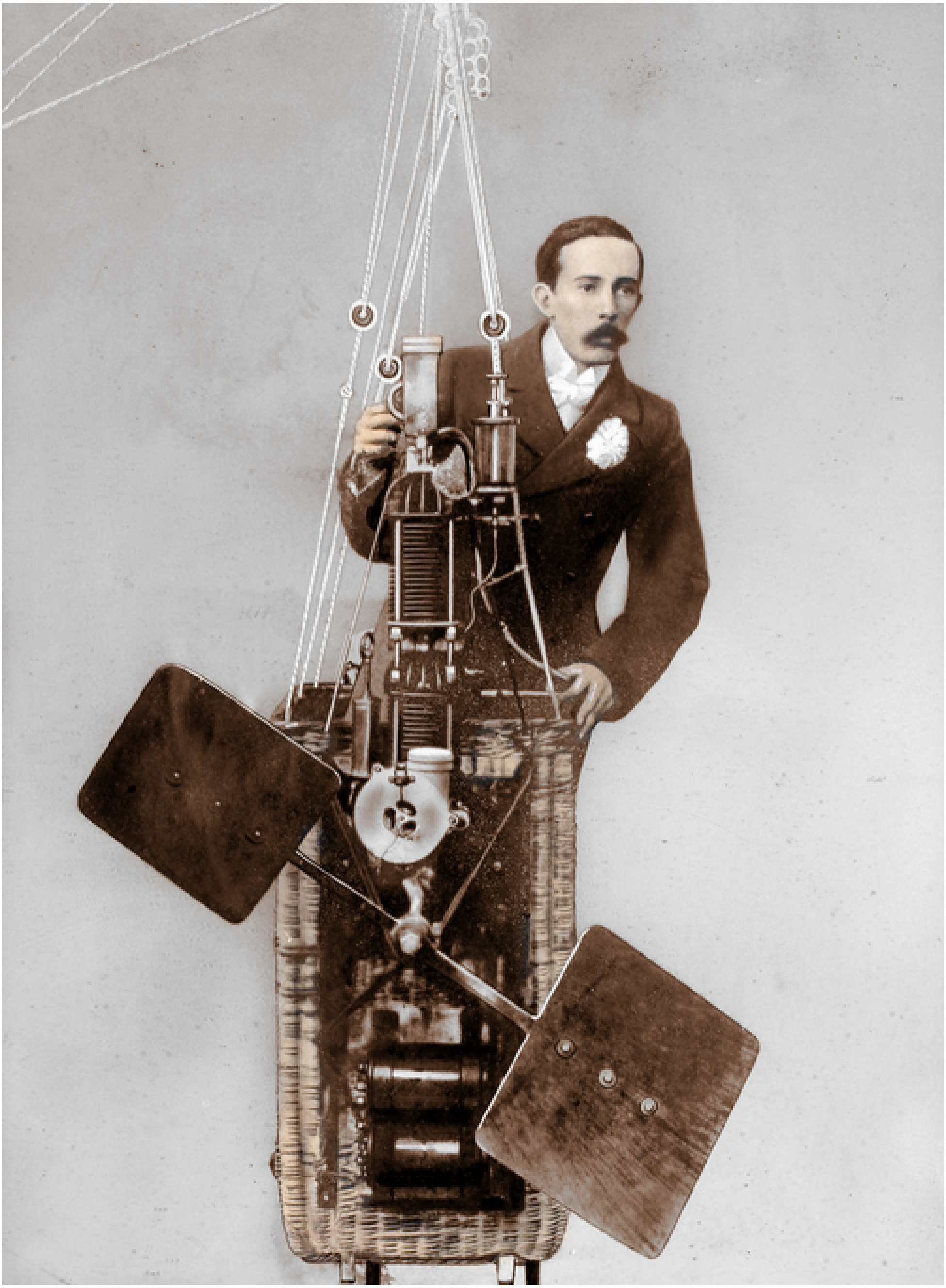
HOW IT FEELS TO NAVIGATE THE AIR.

BY ALBERTO SANTOS-DUMONT.

HOW does it feel to travel in an air-ship? My first impression of aerial navigation was surprise to feel the air-ship going straight ahead. It was astonishing to feel the wind in my face. In spherical balloons we go with the wind and do not feel it. True, in rising and descending, the spherical balloonist feels the friction of the atmosphere, and vertical oscillation often makes the flag flutter; but in all its horizontal movements the ordinary balloon seems to stand still while the earth flies past under it.

This was on the first of all my trips, on Sept. 20th, 1898, the air-ship making only moderate speed. Nevertheless, as it ploughed ahead, the wind struck my face and fluttered my coat as on the deck of a transatlantic liner; though in other respects it will be more accurate to liken aerial to river navigation with a steamboat. It is not at all like sail-navigation ; and all talk about "tacking" is meaningless. If there is any wind at all, it must, regularly, be in a given direction, so that the analogy with a river-current becomes complete. When there is no wind, we may liken it to the navigation of a smooth lake or pond. It will be well to understand this matter.

Suppose that my motor and propeller push me through the air at the rate of twenty miles an hour. I am in the position of a steamboat captain whose propeller is driving him up or down the river at the rate of twenty miles an hour. Imagine the current to be ten miles an hour. If he navigates against the current, he accomplishes ten miles an hour with respect to the shore, though he has been travelling twenty miles an hour through the water. If he goes with the current, he accomplishes thirty miles an hour with respect to the shore, though he has not been going any faster through the water. This is one of the reasons why it is so difficult to estimate the speed of an air-ship.



"I had seen motors ´jump` along the highway. What would mine do in its little basket ?"

Photo by Liébert, Paris.

It is also a reason why air-ship captains will always prefer to navigate, for their own pleasure, in calm weather, and, when they find an air-current against them, will steer obliquely upward or downward to get out of it. Birds do the same thing. The sailing yachtsman whistles for a fair breeze, without which he can do nothing ; but the river-steamboat captain will always hug the shore to avoid the freshet, and will time his descent of the river by the outgoing rather than the incoming tide. We air-shipmen are steamboat captains and not sailing yachtsmen.

The navigator of the air has this one great advantage—he can leave one current for another. The atmosphere above us is full of varying currents. Mounting, he will find an advantageous breeze if not a calm. These are strictly practical considerations, having nothing to do with the air-ship's ability to battle with the breeze when obliged to do it.

Before going on my first trip, I had wondered if I should be seasick. I foresaw that the sensation of mounting and descending obliquely with my shifting weights might be unpleasant ; and I looked forward to a good deal of pitching (*tangage*), as they say on board ship. Of rolling there would not be so much ; but both sensations would be novel in ballooning, for the spherical balloon gives no sensation of movement at all.

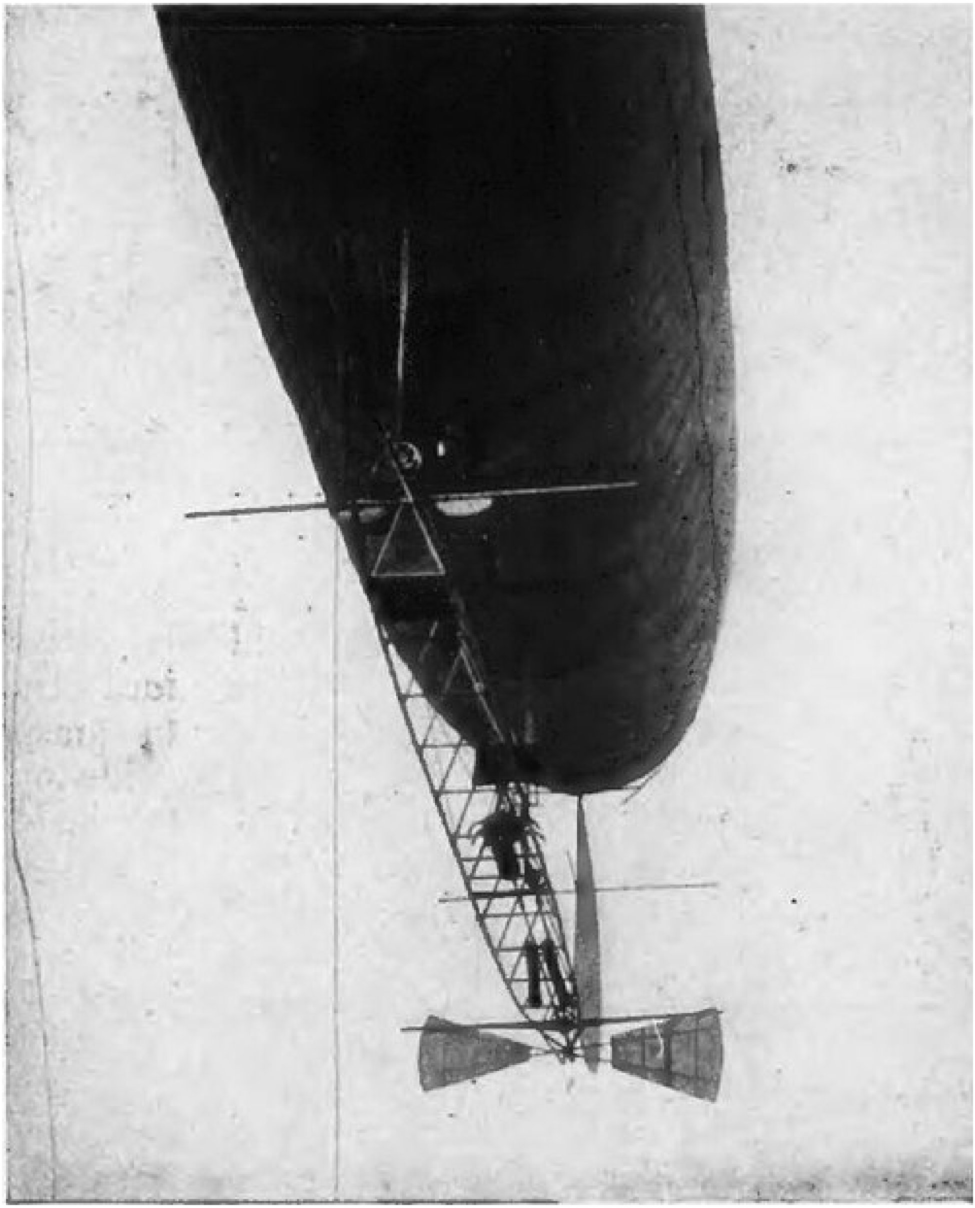
In my first air-ship, however, the suspension was very long, approximating that of a spherical balloon. For this reason there was very little pitching. And, speaking generally, since that time, though I have been told that on this or that trip my airship pitched considerably, I have never been seasick. It may be due in part to the fact that I am rarely subject to this ill upon the water.

I know that what one feels most distressingly at sea is not so much the movement as that momentary hesitation just before the boat pitches, followed by the malicious dipping or mounting, which never comes quite the same, and the shock at top and bottom. All this is powerfully aided by the smells of the paint, varnish, tar, mingled with the odours of the kitchen, the heat of the boilers, and the stench of the smoke and the hold.

In the air-ship there is no smell—all is pure and clean ; and the pitching itself has none of the shocks and hesitations of the boat at sea. The movement is suave and flowing, which is doubtless owing to the lesser resistance of the air-waves. The pitches are less frequent and rapid than those at sea ; the dip is not brusquery arrested : so that the mind can anticipate the curve to its end, and there is no shock to give that queer "empty" sensation to the solar plexus. Furthermore, the shocks of a transatlantic liner are due to first the fore and then the after part of the giant construction rising out of the water to plunge into it again. The air-ship never leaves its medium—the air,—in which it only swings.

This consideration brings me to the most remarkable of all the sensations of aerial navigation. On my first trip it actually shocked me! This is the utterly new sensation of movement in an extra dimension.

Man has never known anything like free vertical existence. Held to the plane of the earth, his movement "down" has scarcely been more than to return to it after a short excursion "up," our minds remaining always on the plane surface even while our bodies may be mounting ; and this is so much the case that the spherical balloonist, as he rises, has no sense of movement, but gains the impression that the earth is descending below him.



In mid-air

Photo by Russell & Sons.

With respect to combinations of vertical and horizontal movements, man is absolutely without experience of them. Therefore, as all our sensations of movement are practically in two dimensions, this is the extraordinary novelty of aerial navigation, that it affords us experiences—not in the fourth dimension, it is true, but in what is practically an extra dimension—the third ; so that the miracle is similar. Indeed, I cannot describe the delight, the wonder and intoxication of this free diagonal movement onward and upward or onward and downward, combined at will with sharp changes of direction horizontally when the air-ship answers to a touch of the rudder ! The birds have this sensation when they spread their great wings and go tobogganing in curves and spirals through the sky!

Por mares nunca d'antes navegados !

(O'er seas hereto unsailed).

The line of our great poet echoed in my memory from childhood. After this first of all my cruises I had it put on my flag.

It is true that spherical ballooning had prepared me for the mere sensation of height ; but that is a very different matter.

It is therefore curious that, prepared on this head as I was, the mere thought of height should have given me my only unpleasant experience. What I mean is this.

The wonderful new combinations of vertical and horizontal movements, utterly out of previous human experience, caused me neither surprise nor trouble. I would find myself ploughing diagonally upward through the air with a kind of instinctive liberty. And yet when moving horizontally—as you would say, in the natural position—a glance downwards at the housetops disquieted me.

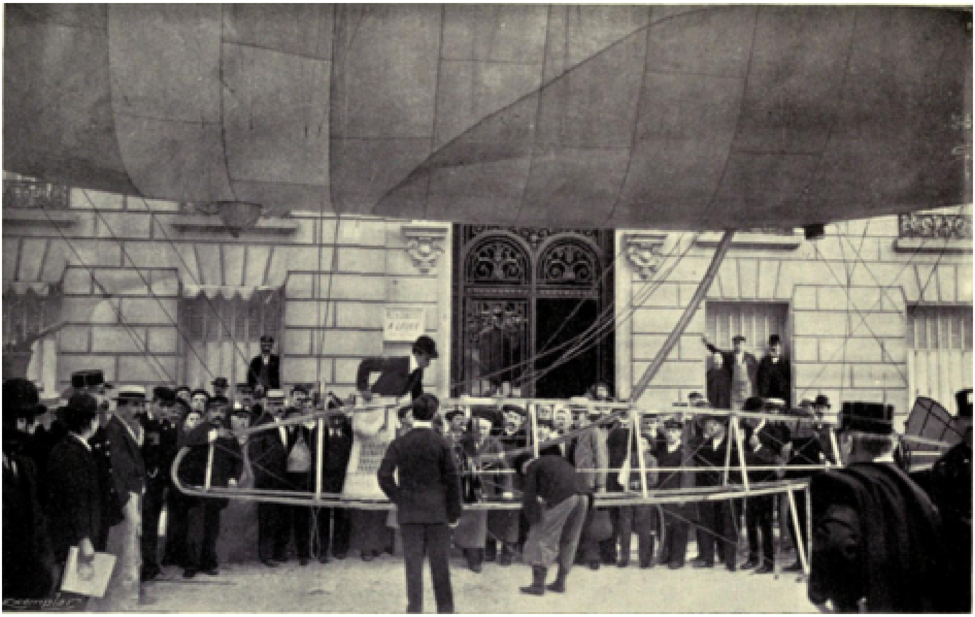
"What if I should fall?" the thought came. The housetops looked so dangerous, with their chimney-pots for spikes. One seldom has this thought in a spherical balloon, because we know that the danger in the air is nil : the great spherical balloon can neither suddenly lose its gas nor burst. My little air-ship balloon had to support not only exterior, but interior pressure as well, which is not the case with a spherical balloon; and any injury to the cylindrical form of my air-ship balloon by loss of gas might prove fatal.

While over the housetops I felt that it would be bad to fall; but as soon as I left Paris and was navigating over the forest of the Bois de Boulogne, the idea left me entirely. Below there seemed to be a great ocean of greenery, soft and safe. It was while over the continuation of this greenery in the grassy *pelouse* of the Longchamps racecourse that my balloon, having lost a great deal of its gas, began to double on itself. Previously I had heard a noise. Looking up, I saw that the long cylinder of the balloon was beginning to break. Then I was astonished and troubled. I wondered what I could do.

I could not think of anything. I might throw out ballast. That would cause the air-ship to rise again, and the decreased pressure of the atmosphere would doubtless permit the expanding gas to straighten out the balloon again, taut and strong. But I remembered that I must always come down again, when all the danger would repeat itself and worse even than before, from the greater quantity of gas I should have lost. There was nothing to do but to go down instantly.

I remember having the sure idea: "If that balloon cylinder doubles any more, the ropes by which I am suspended to it will work at different strengths, and will begin to break, one by one, as I go down!" For the moment I was sure that I was in the presence of death.

Well, I will say it frankly, my sentiment was almost entirely that of waiting and expectation. "What is coming next?" I thought. "What am I going to see and know in the next few minutes? Whom shall I meet first when I am dead?" The thought that I might be meeting my father so soon thrilled me. Indeed, I think that in such moments there is no room either for regret or terror. The mind is too full from looking forward. One is frightened only so long as one has still a chance.

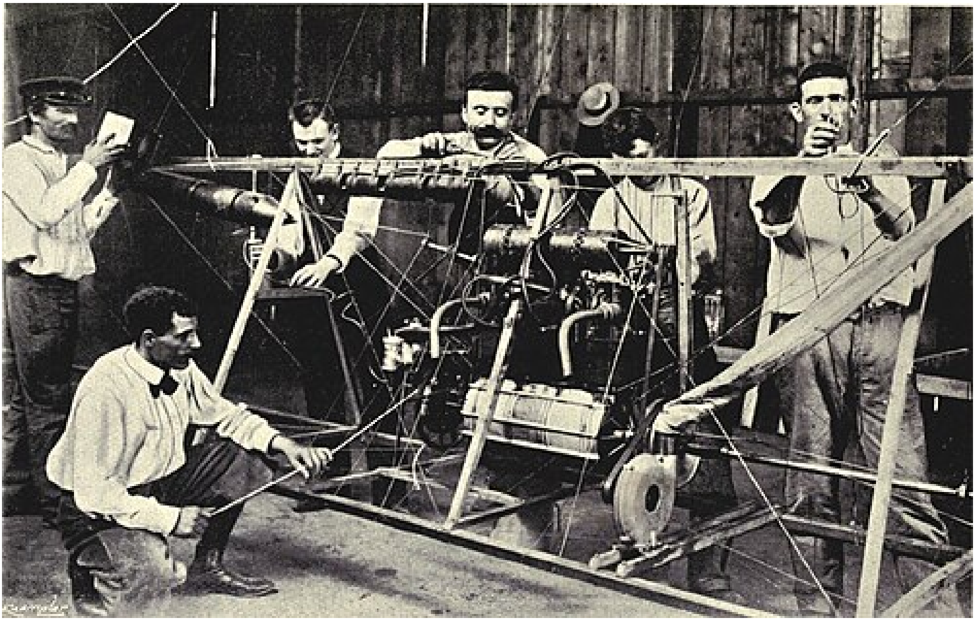


In the streets of Paris.

The descent became a fall. Luckily I was falling in the neighbourhood of the grassy turf of Bagatelle, where some big boys were flying kites. A sudden idea struck me. I cried down to them to grasp the end of my 60-yard-long guide-rope, whose extremity had already touched the ground, and to run as fast as they could with it *against the wind !*

The bright young fellows grasped the idea and the rope-end at the same lucky instant. The effect of this help *in extremis* was immediate and such as I had hoped it might be. By the manœuvre we considerably lessened the velocity of the descent, and so avoided what might otherwise have been broken hones, to say the least. As it was, I had a bad shaking up.

I have been so often and so sincerely warned against what is taken for granted to be the principal and patent danger of operating explosive engines under masses of inflammable gases, that I may be pardoned for stopping a moment to disclaim undue or thoughtless rashness.



A balloon motor.

Photo by P. Raffaels.

Very naturally, from the first, the question of physical danger to myself called for consideration. I was the interested party; and I tried to view the question from all points. Well, the outcome of these meditations was to make me fear fire very little, while doubting other possibilities against which no one ever dreamed of warning me!

I remember that while working on this the first of all my air-ships—in a little carpenter's-shop of the Rue du Colisée, I used to wonder how the vibrations of the petroleum motor would affect the system when it should get into the air.

In those days we did not have the noiseless automobiles, free from great vibration, of the present. Nowadays even the colossal 80-and 90-horse-power motors of the latest racing types can be started and stopped as gently as those great steel hammers in iron foundries, whose engineers make a trick of cracking the top of an egg with them without breaking the rest of the shell.

My tandem-motor of two cylinders working the same connecting-rod and fed by a single carburator produced $3\frac{1}{2}$, horse-power—at that time a considerable force for its weight; and I had no idea how it would act off *terra firma*. I had seen motors "jump" along the highway. What would mine do in its little basket that weighed almost nothing, and suspended from a balloon that weighed less than nothing?

You know the principle of these motors? One may say that there is gasoline in a receptacle. Hot air passing through it comes out mixed with gasoline gas, ready to explode. You give a whirl to a crank and the thing begins working automatically. The piston goes down, driving combined gas and air into the cylinder. Then the piston comes back and compresses it. At that moment an electric spark is struck. An explosion follows instantly ; and the piston goes down, producing force. Then it goes up, throwing out the product of combustion. Thus, with the two cylinders, there was one explosion for every turn of the shaft.

Over the Bois de Boulogne.

Photo by Raffaele.

Wishing to have my mind clear on the question, I took my tricycle just as it was after I had left the Paris-Amsterdam race; and, accompanied by a capable companion, I steered it to a lonely part of the Bois de Boulogne. There, in the forest, I chose a great tree with low-hanging limbs. From two of them we suspended the motor-tricycle by three ropes. When we had well established the suspension, my companion aided me to climb up and seat myself on the tricycle saddle. I was as in a swing. In a moment I would start the motor and learn something of my future success or failure.

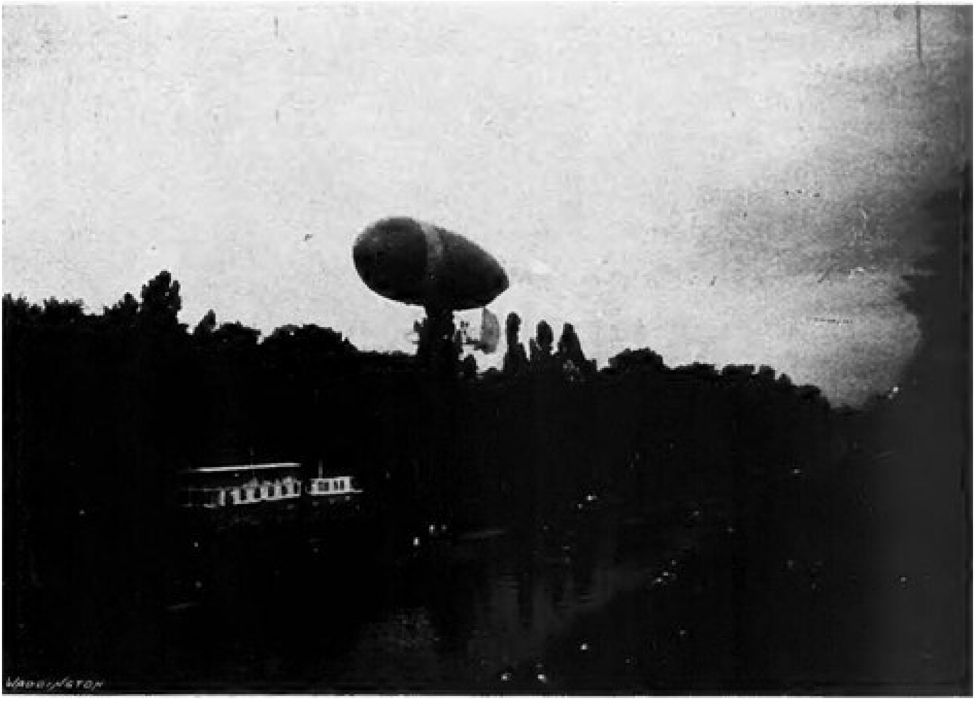
Would the vibration of the explosive engine shake me back and forth, strain at the ropes until it had unequalised their tension, and then break them one by one? Would it jar the interior air-balloon's pump and derange the big balloon's valves? Would it continually jerk and pull at the silk hems and the thin rods which were to hold my basket to the balloon? Free from the steadying influence of the solid ground, would the jumping motor jar itself until it broke? and, breaking, might it not explode?

All this and more had been predicted by the professional aeronauts; and I had as yet no proof outside of reasoning that they might not be right on this or that topic.

I started the motor. I felt no particular vibration; and I was certainly not being shaken. I increased the speed—and felt *less* vibration! There could be no doubt about it: there was less vibration in this light-weight basket hanging in the air than I had regularly felt while travelling by its means on the tricycle. It was my first triumph in the air!

I will say frankly that, as I rose in the air on my first trip, I had no fear of fire. What I feared was that the balloon might burst by reason of its interior pressure. I still fear it. Before going up I had minutely tried the valves. I still try them minutely before each of my trips.

The danger, of course, was that the valves might not work adequately, in which case the expanding of the gas as the balloon rose would cause the dreaded explosion. Here is the great difference between spherical and dirigible balloons. The spherical balloon is always open. When it is taut with gas it is shaped like an apple; when it has lost part of its gas, it takes the shape of a pear: but in each case there is a great hole in the bottom of the spherical balloon--where the stem of the apple or the pear would be—and it is through this hole that the gas has opportunity to ease itself in the constant alternations of condensation and dilatation. Having such a free vent, the spherical balloon runs no risk of bursting in the air; but the price paid for this immunity is great loss of gas and, consequently, a fatal shortening of the spherical balloon's stay in the air. Some day a spherical balloonist will close up that hole. Indeed, they already talk of doing it.



An alarm of fire. The flame was extinguished with a Panama hat.

I was obliged to do it in my air-ship balloon, whose cylindrical form must be preserved at all cost. For me there must be no transformations as from apple to pear. Interior pressure only could guarantee me this. The valves to which I refer have, since my first experiments, been of all kinds, some very ingeniously interacting, others of extreme simplicity. But their object in each case has always been the same—to hold the gas tight in the balloon up to a certain pressure and then let only enough of it out to relieve dangerous interior pressure. It is easy to realise, therefore, that, should these valves refuse to act adequately, the danger of bursting would be there.

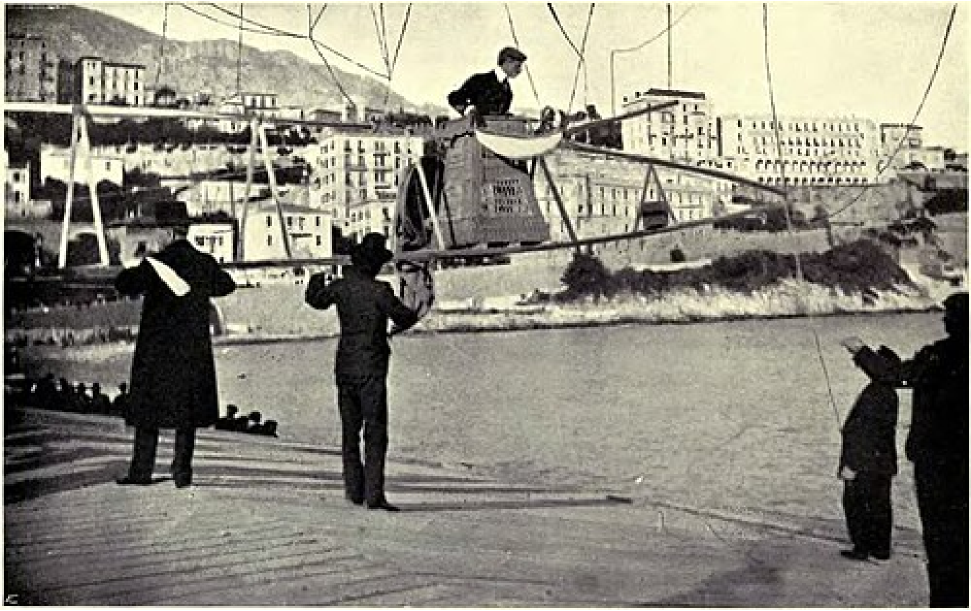
This possible danger I acknowledge to myself; but it had nothing to do with fire from the explosive motor. Yet, during all my preparations, and up to the moment of calling "Let go all!" the professional aeronauts, completely overlooking this weak point of the air-ship, continued to warn me against fire.

"Do we dare strike matches in the basket of a spherical balloon?" they asked. "Do we even permit ourselves the solace of a cigarette on trips that last for many hours?"

To me the cases did not seem the same. In the first place, why should one not light a match in the basket of a spherical balloon? If it be only because the mind vaguely connects the ideas of gas and flame, the danger remains as ideal. If it be because of a real possibility of igniting gas that has escaped from the free hole in the stem of the spherical balloon, it would not apply to me. My balloon, hermetically closed except when excessive pressure should let either air or a very little gas escape through one of the automatic valves, might for a moment leave a little trail of gas *behind* it as it moved on horizontally or diagonally, but there would be none in front where the motor was.

In this first air-ship I had placed the gas escape-valves even farther from the motor than I place them to day; the suspension-cords being very long, I hung in my basket far below the balloon. Therefore I asked myself: "How could this motor, so far below the balloon and so far in front of its escape-valves, set fire to the gas enclosed in it, when such gas is not inflammable until mixed with air?"

On this first trial—as in most since—I used hydrogen gas. Undoubtedly, when mixed with air, it is tremendously inflammable. But it must first mix with air. All my little balloon models are kept filled with hydrogen; and, so filled, I have more than once amused myself by burning *inside them*, not their hydrogen but the oxygen of the atmosphere. All one has to do is to insert in the balloon model a little tube to furnish a jet of the room's atmosphere from an air-pump, and light it with the electric spark. Similarly, should a pin-prick have made ever so slight a vent in my air-ship balloon, the interior pressure would have sent out into the atmosphere a long thin stream of hydrogen that *might* have ignited—had there been any flame near enough to do it. But there was none.



The balloon house at Monaco.

Photo by Numa Blanc.

This was the problem. My motor did undoubtedly send out flames for, say, half a yard around it. They were, however, mere flames, not still-burning products of incomplete combustion like the sparks of a steam-engine fed by coal. This admitted, how was the fact that I had a mass of hydrogen unmixed with air and well secured in a tight envelope so high above the motor to prove dangerous?

Turning the matter over and over in my mind, I could see but one dangerous possibility from fire. This was the possibility of the petroleum reservoir itself taking fire by a *retour de* *flamme* from the motor. During five years, I may here say in passing, I enjoyed complete immunity from the *retour de flamme*. Then, in the same week in which Mr. Vanderbilt burned himself so severely, on July 6th, 1903, the same accident overtook me in my little " No. 9 " runabout air-ship, just as I was crossing the Seine to land on the Ile de Puteaux. I promptly extinguished the flame with my Panama hat . . . without other incident.

For reasons like these I went up on my first air-ship trip without fear of fire; but not without doubt of a possible explosion due to insufficient working of my balloon's escape-valves. Should such a "cold" explosion occur, doubtless the flame-spitting motor would ignite the mass of mixed hydrogen and air that would surround me. But it would have no decisive influence on the result. The "cold" explosion itself would doubtless be sufficient. . . .

Now, after five years of experience, and in spite of the *retour de flamme* above the Ile de Puteaux, I continue to regard the danger from fire as practically nil ; but the possibility of a "cold" explosion remains always with me, and I must continue to purchase immunity from it at the cost of vigilant attention to my gas escape-valves. Indeed, the possibility of the thing is greater technically now than in the early days which I describe. My first air-ship was not built for speed: consequently it needed very little interior pressure to preserve the shape of its balloon. Now that I have great speed, as in my "No. 7," I must have enormous interior pressure to withstand the exterior pressure of the atmosphere in front of the balloon as I drive against it.

A flight at Monaco.

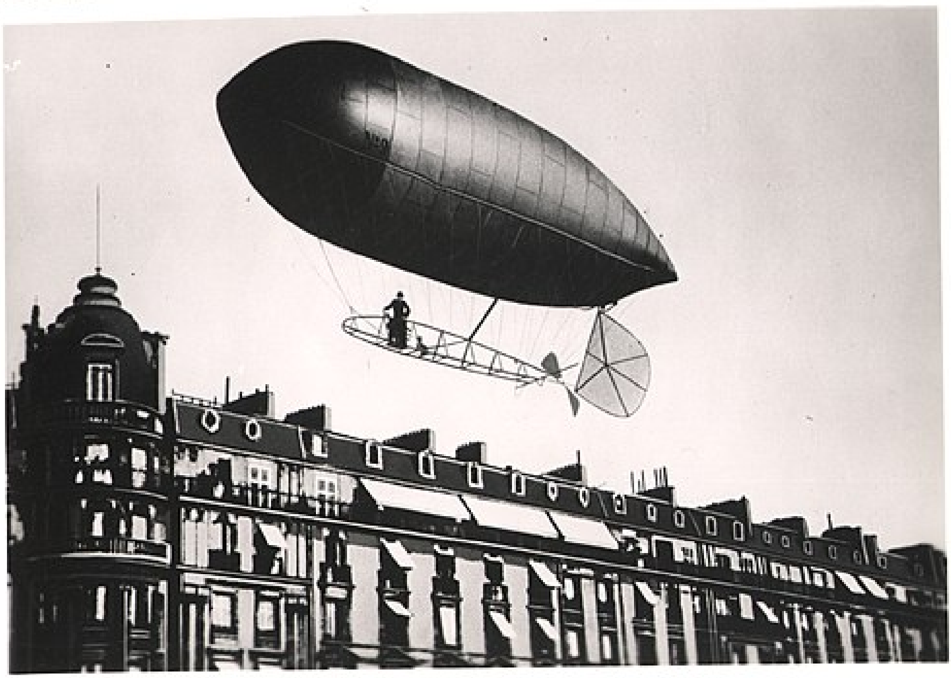
Photo by Numa Blanc.

The Speed of Air-ships.

The speed problem is, doubtless, the first of all air-ship problems. Speed must always be the final test between rival air-ships; and until high speed shall be arrived at, certain other problems of aerial navigation must remain in part unsolved. For example, take that of the air-ship's pitching (*tangage*). I think it quite likely that a critical point in speed will be found, beyond which on each side the pitching will be practically nil. When going slowly, or at moderate speed, I have experienced no pitching, which, in an air-ship like my "No. 6," seems always to commence at 25 to 30 kilometres per hour through the air. Now, probably, when one passes this speed considerably—say at the rate of 50 kilometres per hour—all *tangage*, or pitching, will be found to cease again.

Speed must always be the final test between rival air-ships, because in itself it sums up all other air-ship qualities, including "stability." At Monaco, when I made my best speed, however, I had no rivals to compete with. Furthermore, my prime study and amusement there was the beautiful working of the maritime guide-rope; and this guide-rope, dragging through the water, must of necessity retard whatever speed I made. There could be no help for it. Such was the price I must pay for automatic equilibrium and vertical stability—in a word, easy navigation—so long as I remained the sole and solitary navigator of the air-ship.

Nor is it an easy task to calculate an air-ship's speed. On these flights up and down the Mediterranean coast, the speed of my return to Monaco, wonderfully aided by the wind, could bear no relation to the speed out, retarded by the wind; and there was nothing to show that the force of the wind, going and coming, was constant. It is true that on these flights one of the difficulties standing in the way of such speed calculations the "shoot the chutes" (*mentagnes Russes*) of ever-varying—altitude was done away with by the operation of the marine guide-rope; but, on the other hand, as has been said, the dragging of the guide-rope's weight through the water, acted as a very effectual brake. As the speed of the air-ship is increased, this brake-like action of the guide-rope (like that of the resistance of the atmosphere itself) grows, not in proportion to the speed, but in proportion to the square of it.



"*One can guide-rope in the centre of Paris.*"

Photo by Simons.

On these flights along the Mediterranean coast the easy navigation afforded me by the maritime guide-rope was purchased, as nearly as I could calculate, by the sacrifice of about six kilometres per hour of speed; but, with or without maritime guide-rope, the speed calculation has its own almost insurmountable difficulties.

From Monte Carlo to Cap Martin at ten o'clock of a given morning may be quite a different trip from Monte Carlo to Cap Martin at noon of the same day ; while from Cap Martin to Monte Carlo, except in perfect calm, must always be a still different proposition. Nor can any accurate calculations be based on the markings of the anemometer, an instrument which I nevertheless carried. Out of simple curiosity I made note of its readings on several occasions during my trip of February 12th, 1902. It seemed to be marking between 32 and 37 kilometres per hour; but the wind, complicated by side-gusts, acting at the same time on the air-ship and the wings of the anemometer windmill—*i.e.* on two moving systems whose inertia cannot possibly be compared—would alone be sufficient to falsify the result.

When, therefore, I state that, according to my best judgment, the average of my speed through the air on these flights was between 30 and 35 kilometres per hour, it will be understood that it refers to speed through the air whether the air be still or moving, and to speed retarded by the dragging of the maritime guide-rope. Putting this adverse influence at the moderate figure of 7 kilometres per hour, my speed through the still or moving air would be between 37 and 42 kilometres per hour.

Where speed calculations have their real importance is in affording necessary data for the construction of new and more powerful air-ships. Thus the balloon of my racing "No. 7," whose motive-power depends on two propellers each 4 metres in diameter and worked by a 60-horse-power motor with a water-cooler, has its envelope made of two layers of the strongest French silk, four times varnished, capable of standing, under dynamometric test, a traction of 3000 kilogrammes per linear metre.

I will now try to explain why the balloon-envelope must be made so very much stronger as the speed of the air-ship is designed to be increased; and in so doing I shall have to reveal the unique and paradoxical danger that besets high-speed dirigibles, threatening them, not with beating their heads in against the outer atmosphere, but with blowing their tails out behind them!

Although the interior pressure in the balloons of my air-ships is very considerable, as balloons go—the spherical balloon, having a hole in its bottom, is under no such pressure—it is so little in comparison with the general pressure of the atmosphere, that we measure it, not by "atmospheres," but by centimetres or millimetres of water-pressure—*i.e.* the pressure that will send a column of water up that distance in a tube. One "atmosphere" means one kilogramme of pressure to the square centimetre; and it is equivalent to 10 metres of water-pressure, or, more conveniently, 1000 centimetres of "water." Now, supposing the interior pressure in my slower "No. 6" to have been close up to 3 centimetres of water (it required that pressure to open its gas-valves), this would have been equivalent to $\frac{1}{333}$ of an atmosphere ; and as one atmosphere is equivalent to a pressure of 1000 grammes (1 kilogramme) on one square centimetre, the interior pressure of my "No. 6" would have been $\frac{1}{333}$ of 1000 grammes, or 3 grammes. Therefore on one square metre (10,000 square centimetres) of the stem, or head, of the balloon of my "No. 6,"the interior pressure would have been 10,000 multiplied by 3, or 30,000 grammes—*i.e.* 30 kilogrammes.


WADDINGTON

How is this interior pressure maintained without being exceeded? Were the great exterior balloon filled with hydrogen, and then sealed up with wax at each of its valves, the sun's heat might expand the hydrogen, make it exceed this pressure and burst the balloon; or should the sealed balloon rise high, the decreasing pressure of the outer atmosphere might let its hydrogen expand—with the same result. The gas-valves of the great balloon, therefore, must *not* be sealed; and, furthermore, they must always be very carefully made, so that they will open of their own accord at the required and calculated pressure.

This pressure (of 3 centimetres in the "No. 6"), it ought to be noted, is attained by the heating of the sun, or by a rise in the altitude, only when the balloon is completely filled with gas. What may be called its working-pressure—about one-fifth lower—is maintained by the rotary air-pump. Worked continually by the motor, it pumps air constantly into the small interior balloon. As much of this air as is needed to preserve the outer balloon's rigidity remains inside the little interior balloon; but all the rest pushes its way out into the atmosphere again through its air-valve—which opens at a little less pressure than do the gas-valves.

Let us now return to the balloon of my "No. 6." The *interior* pressure on each square metre of its stem-head being continuously about 30 kilogrammes, the silk material composing it must be normally strong enough to stand it ; nevertheless it will be easy to see how it becomes more and more relieved of that interior pressure as the air-ship gets in motion and increases speed. Its striking against the atmosphere makes a counter-pressure *against the outside* of the stem-head. Up to 30 kilogrammes to the square metre, therefore, all increase in the air-ship's speeds tends to reduce strain—so that the faster the air-ship goes, the less will it be liable to burst its head!

How fast may the balloon be carried on by motor and propeller before its head-stem strikes the atmosphere hard enough to more than neutralise the interior pressure? This, too, is a matter of calculation; but, to spare the reader, I will content myself with pointing out that my flights over the Mediterranean proved that the balloon of my "No. 6" could safely stand a speed of 36 to 42 kilometres per hour without giving the slightest hint of strain; but had I wanted an air-ship of the proportions of the " No. 6 " to go twice as fast, under the same conditions, its balloon must have been strong enough to stand four times its interior pressure of 3 centimetres of "water," because the resistance of the atmosphere grows, not in proportion to the speed, but in proportion to the square of the speed.

The balloon of my "No. 7" is not, of course, built in the precise proportions of that of my "No. 6"; but I may mention that it has been tested to resist an interior pressure of much more than 12 centimetres of "water"—in fact, its gas-valves open at that pressure only. This means just four times the interior pressure of my "No. 6." Comparing the two balloons in a general way, it is obvious, therefore, that with no risk and, indeed, with positive relief from outside pressure on its stem, or head, the balloon of my "No. 7" may be driven twice as fast as my easy-going Mediterranean pace of 42 kilometres per hour—or 80 kilometres!

I say with relief from outside pressure on the balloon's stem, or head; and this brings us to the unique and paradoxical weakness of the fast-going dirigible. Up to the point where the exterior shall equal the interior pressure, we have seen how every increase of speed actually guarantees safety to the stem of the balloon. Unhappily it does not remain true of the balloon's stern-head. On it the interior pressure is also continuons; but speed cannot relieve it. On the contrary, the *suction* of the atmosphere behind the balloon as it speeds on increases also, almost in the same proportion as the pressure caused by driving the balloon against the atmosphere. And this suction, instead of operating to neutralise the interior pressure on the balloon's stern-head, *increases* the strain just that much, the pull being added to the push. Paradoxical as it may seem, therefore, the danger of the swift dirigible is to blow its tail out rather than its head in!

How is this danger to be met? Obviously by strengthening the stern part of the balloon-envelope. We have seen that when the speed of my "No. 7" shall be just great enough to completely neutralise the interior pressure on its stem, or head, the strain on its stern-head will be practically doubled.

For this reason I have doubled the balloon material at this point.

I have reason to be careful of the balloon of my "No. 7." In it the speed problem will be attacked definitively. It has two propellers, each 5 metres in diameter. One will push, as usual, from the stern, while the other will pull from the stem, as in my "No. 4." Its 60-horse-power Clément motor will—if my expectations are fulfilled—give it a speed of between 70 and 80 kilometres per hour. In a word, the speed of my "No. 7" will bring us very close to practical everyday aerial navigation; for, as we seldom have a wind blowing as much, even, as 50 kilometres per hour, such an air-ship will surely be able to go out daily during more than ten months in the twelve.

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