An Aneroid Aloft

Why old barometers and barographs dislike airmail

Leo Shirokov · 02 July 2026

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Anyone who takes a bag of crisps aboard an aircraft can perform this striking little experiment: set the sealed bag in front of you and watch it swell up as though a smug balloon had taken up residence inside. The air within stays trapped at ground level — sealed at the factory during packing; outside, as the aircraft climbs, the pressure falls. The bag knows nothing of the words "pressure gradient" or "standard atmosphere," yet it demonstrates them flawlessly.

The very physics that harmlessly inflates a foil bag can ruin an instrument that has survived a hundred years. For a collector or a museum keeper the question is anything but abstract: what will happen to a particular aneroid barometer of the 1870s, or to a barograph of the early twentieth century, if it is sent by airmail? The answer is unpleasant in its practicality. The aneroid's transmission jams once it reaches its extreme position, while the aneroid capsule may deform under the growing pull of external and internal springs left without the atmosphere to push back against them.

For me this question was never purely theoretical. Over years of working with historical barometers and barographs I have repeatedly seen instruments with an inexplicably shifted zero, with bent levers, a jammed transmission, or damaged capsules, even though outwardly they looked almost flawless. In most cases such damage is of course caused either by mechanical impact — a fall, perhaps — or by over-tightening the barometer's calibration screw. Yet not all of these faults can be explained by those factors. Gradually a suspicion took shape that some of this damage might have appeared not over a century of use, but far more recently — during modern transport. It was precisely the attempt to understand this mechanism that led me to study what happens to an aneroid inside an aircraft.

The Barometric Step: How Pressure Falls with Altitude

Atmospheric pressure is the weight of the column of air above us. The higher we climb, the less air remains overhead and the lower the pressure. It falls not linearly but exponentially — a consequence of the hydrostatic equation together with the gas equation of state (the barometric formula). The scale height of a uniform atmosphere is about 8.4 km. Near the ground, therefore, the pressure changes by roughly 1 hPa for every 8 metres of ascent; at around 5–6 km it is already about half; and at some 11 km the standard atmosphere gives about 226 hPa.

This is no museum exotica but the ordinary geography of air freight. In a pressurised passenger cabin the pressure is not that of sea level: aviation norms usually speak of an equivalent altitude of up to 8,000 ft, that is about 2,440 m, corresponding to a pressure of the order of 750 hPa. In unpressurised or weakly pressurised holds, and under cargo arrangements generally, the pressure can be far lower — hundreds of hectopascals. To this is added the cold: in the standard atmosphere the tropopause is around −56.5 °C, while real cargo holds depend on the aircraft type, on heating, and on where the cargo is stowed. In other words, up there the instrument is asked to measure a pressure five times smaller than the one its scale was designed for. The needle has long lain against its lower stop, and the atmosphere keeps thinning.

Pressurising the Hold: Sealed or Not?

At altitude the engines compress air in the compressor — part of this hot compressed air ("bleed air," drawn from behind the blades) is tapped off before the combustion chamber, cooled, conditioned, and fed continuously into the fuselage. At the rear sits the outflow valve, which constantly bleeds air overboard. The system governs how far it opens: close it more and the pressure rises; open it wider and it falls.

Wide-body commercial freighters (Boeing 747F, 777F, 767F; Airbus A330F, and so on) are almost always pressurised. The reason is simple and economic: they are all cargo variants of passenger machines. Freighters such as the 777F and 747F enjoy an advantage: being derived from passenger aircraft, they carry from the outset a pressurisation system originally designed for people.

Specialised heavy-lift transports are another matter. The An-124 has a fully pressurised upper passenger deck for 88 people, yet, unlike the C-5 Galaxy, its main cargo deck is only partially pressurised. The An-124's upper cabins hold a differential of 7.82 psi — so the cargo deck receives roughly half the pressurisation of the occupied zones (≈446 hPa, or 335 mmHg, at cruise). Most of the time this aircraft carries industrial equipment that has no need of a comfortable environment.

General aviation and regional aircraft are, in most cases, unpressurised: they fly below 10,000 ft (≈3,000 m), where pressurisation is not required. Some freight is delivered to small stations by smaller aircraft that never climb above 10,000 ft, so not every consignment travels in a pressurised aeroplane. Feeder flights between minor airports are often flown by unpressurised turboprops. The Beluga's main deck is not pressurised at all; in such an unpressurised hold (Beluga, small turboprops, old conversions) the cruise pressure is about 170 mmHg (226 hPa). The sender of an airmail parcel usually neither knows nor controls which aircraft, and which hold, will carry the package on each leg of its route.

Pressure Inside the Sealed Cabin

For most commercial aircraft — passenger and freight alike — a single standard applies, set by the American regulator. Under FAR 25.841(a), pressurised cabins and compartments intended to be occupied must maintain a cabin altitude of no more than 8,000 ft under normal operating conditions at the aircraft's maximum operating altitude.

8,000 ft (2,440 m) corresponds, by the standard-atmosphere table, to roughly 750–755 hPa (565–600 mmHg), though in practice 750–790 hPa is more usual — about −30 % relative to sea level. The differential between cabin and outside air varies with aircraft type; typical values run from 540 to 650 hPa (7.8–9.4 psi). At a flight altitude of 39,000 ft (11,887 m) the cabin pressure is held automatically at a level corresponding to about 6,900 ft (2,100 m) — around 790 hPa.

Lower cargo holds receive their pressure not directly from the air-conditioning system but through equalising valves from the passenger cabin. The pressure in cargo containers usually corresponds to about 75 kPa, equivalent to the atmospheric pressure at an altitude of 2,438 m — that is, the same 8,000 ft ceiling.

A nuance for the Boeing 747: the forward cargo hold is heated, the aft hold is not; this is why live animals and pets are stowed forward. The pressure in both is the same — only the temperature differs. Cargo zones on the main deck of freighters usually hold 15–25 °C at cruise, though this depends on the aircraft type; lower-deck holds are often colder, 5–15 °C. According to Federal Aviation Administration measurements (1996), the temperatures inside pressurised baggage holds were 65–70 °F (18–21 °C), comparable to the passenger compartments. An important nuance: the conditioned air reaches the cargo holds from the passenger cabin already "used"; the holds are less well insulated and have no heating of their own, so in the lower "belly" holds it is noticeably colder in winter.

The process of pressurisation and the climb to cruising level looks, in broad outline, like this. The cabin-pressure control systems begin to pressurise the aircraft (to "lower the cabin altitude") even before lift-off — while taxiing to the runway or at the start of the take-off roll — in order to seal all the doors and improve comfort at the start of the climb; this initial stage is sometimes called cabin pre-pressurisation. The very closing of the doors usually lowers the cabin altitude by about 40 ft below field elevation, owing to the pressure differential across the outflow valve. Then pre-pressurisation begins (≈0.86 kPa, 0.125 psi) at a rate of 300 ft/min until the pressure reaches a value corresponding to 150 ft below field elevation. As the aircraft climbs to cruise, the cabin altitude rises more slowly than the aircraft's, so that on reaching the cruising level (37,000 ft, say) the cabin arrives at a target altitude of about 7,000 ft. On descent the process runs in reverse: the cabin altitude falls so that the cabin reaches field elevation at roughly the same moment as the aircraft. That is, by the time the wheels touch down the aircraft and cabin are already "at the same altitude." After landing the outflow valves open fully within 55 seconds, equalising the pressure with the atmosphere — and only then may the doors be opened.

Now, knowing how the cabin behaves, let us return to the bag of crisps: it explains all the mechanics of the damage that follows more vividly than any diagram.

On the ground, before take-off, the pressure inside the cabin is ≈1013 hPa, and inside the bag it is likewise ≈1013 hPa (it was sealed at the factory at that same pressure). There is no differential — the bag is not inflated. For an ideal gas at roughly constant temperature, PV = nRT holds; when the external pressure decreases, the flexible envelope increases its volume until the pressures inside and out are again in balance. The pre-pressurisation before take-off is a tiny differential, literally 0.86 kPa (0.125 psi) above atmospheric; so small that it has no effect on the bag at all. The point of that micro-differential is different — to stabilise the valve-control system and to create a slight backing force so that the doors do not "pop" against the ears when closed. But during the climb the cabin pressure sinks slowly from 1013 towards 750 hPa, while the bag is still sealed at 1013 hPa; the pressure difference grows, and the bag inflates gradually over the course of the ascent. By cruising altitude the differential is about 263 hPa — the bag is inflated to the full, and sometimes bursts.

It is curious that an everyday experience should turn out to be the clearest explanation of a complex engineering problem. We are so used to the crisp bag swollen after a flight that we have stopped seeing it as a physical experiment. Yet at that moment it demonstrates the very laws that govern the sensing elements of old barometers. Sometimes the most convincing illustrations are found not in a laboratory but in each of our own hands.

The Instrument Beyond Its Scale

On the ground, inside and outside the aircraft, the pressure is ≈760 mmHg (1013 hPa). At 11 km the outside pressure is ≈226 hPa — nearly a vacuum. The pressurisation system holds the pressure inside at ≈750 hPa. A typical aneroid scale, meanwhile, is 950–1050 hPa = 713–788 mmHg (≈28.0–31.0 inHg), and its lower mark falls at 713 mmHg. Even in the most favourable case — a pressurised 777F — the instrument finds itself at ≈563–600 mmHg, that is 115–150 mm below the lower edge of its scale. The barometer's needle, or the barograph's lever, lies against its stop while the aneroid capsule keeps opening — for this is still a pressure beyond the lower mark of any standard barometer's scale. The mechanism undergoes a full overload, and the condition "the aircraft is pressurised" does not save it. An antique barometer lying in a cargo hold or cabin passes through the whole range of pressures — from a notional ground value (~1013 hPa) to 750–790 hPa at cruise — smoothly but inexorably, over the 15–30 minutes of the climb. But 750 hPa is already below the lower boundary of the scale (950 hPa), and it is precisely this threshold that leads to damage of the instrument's mechanics.

The Aneroid Box and Its Transmission

The heart of the instrument is the aneroid box — also the capsule, or the Vidie cell (after Lucien Vidie, who patented the design in 1844). It is a thin-walled metal box with corrugated faces, from which the air has been pumped out: inside is not a perfect vacuum but a stable rarefaction — usually a few per cent of an atmosphere. The corrugations set a preferred direction of deformation (the faces move towards and away from each other), increase the working travel, and linearise the response.

An opened brass aneroid capsule.

An evacuated box tends to collapse under atmospheric pressure, and what keeps it from doing so is an elastic restoring force. Here lies the first important branching of designs, for that force can be arranged in three different ways, and each behaves in its own way at altitude.

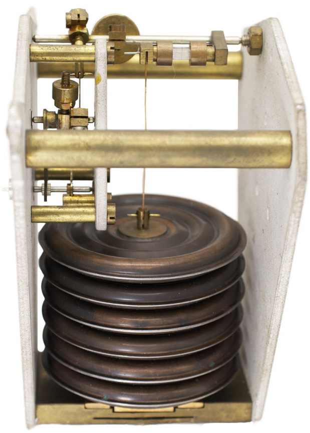
External spring. The first variant, a classic of the early instruments, is a helical spring that tensions the capsule through a massive lever, as in Lucien Vidie's earliest aneroids. The second is a flat, curved C-spring stretching the walls of the capsule — the best-known and most widely used means of tensioning aneroid capsules. In both cases the spring lies outside the sensing element, pulling the box "open," balancing the atmosphere and forming a single measuring unit. In this arrangement the aneroid capsule serves more as a sensitive membrane, while the main restoring work is done by the spring; it is the spring that sets the operating point and the span of the scale.

A steel C-spring on a cast-iron yoke.

Internal spring. Here the spring is hidden within the capsule itself. It may be an ordinary helical spring set in the centre of the capsule between its walls, or a spring made of two curved steel plates meeting end to end — the sort found in barographs. The logic is the same as with an external spring, but the layout is more compact.

An opened aneroid capsule with an internal spring.

Self-elastic capsule. A later and more elegant approach: there is no separate spring at all, the restoring force being supplied by the elasticity of the corrugated metal itself. In such an instrument the capsule is not merely a "box with a vacuum" but a spring of complex shape. This calls for a special metal — one with a high elastic limit, low hysteresis, and resistance to fatigue. The canonical choice is beryllium bronze (beryllium copper), more rarely phosphor bronze. Precision aneroid barometers are built precisely this way: a stack of several self-elastic capsules assembled along a common axis, with no separate spring — hence less friction, wear, and drift.



A stack of self-elastic capsules from a Fuess precision barometer.

The capsule's own travel is microscopic. The full "weather" range, from a deep cyclone (≈950 hPa) to a strong anticyclone (≈1050 hPa), shifts the face of a capsule about 50 mm in diameter by roughly 0.3 mm. To turn these three tenths of a millimetre into a legible sweep of the needle requires a transmission with colossal magnification — of the order of 200:1, or even 400:1. It is realised either by a system of levers with a fusee chain wound onto the needle's arbor (in which case a fine hairspring takes up the play in the bearings), or by a toothed drive — a sector and pinion (rack-and-pinion).

The Limits of the Dial

The narrowness of the barometric scale on the dial is a direct consequence of the magnification the transmission imparts to the movement of the capsule wall. Since the capsule's tiny travel is stretched around the whole circumference of the dial, only a narrow band of pressures fits within that travel. A typical domestic or meteorological aneroid at the surface covers the weather interval of about 950–1050 hPa. In the units familiar to old instruments this is roughly 712.6–787.6 mmHg, or 28.05–31.01 inches of mercury. The reference equality: 1013.25 hPa = 760 mmHg = 29.92 inHg.

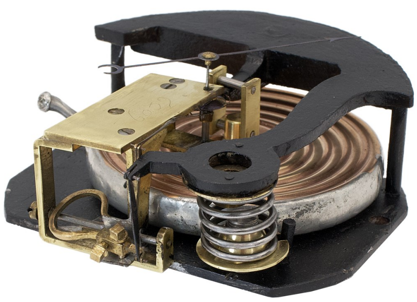
Going beyond the limit of the scale is therefore no aesthetic nuisance. It means that the sensing element keeps moving while the indicating mechanism is already approaching the geometric end of its safe travel: the needle (or pen) reaches the edge of the scale and comes up against a mechanical stop. The capsule still has travel in reserve — but there is nowhere left to transmit it. All further deformation of the capsule bears against the jammed transmission.

The Mechanics of the Damage

The capsule's deformation is proportional to the "outside minus inside" difference. At sea level the outside is ≈1013 hPa and the inside ≈50 hPa, a difference of ≈963 hPa — the capsule is strongly compressed relative to its free (unloaded) form, and its free form is precisely the most "open" one. As we climb and the outside pressure falls, the difference decreases, and the self-elastic capsule does not become over-strained but, on the contrary, relaxes, returning smoothly to its natural open form. The maximum mechanical stress in such a capsule falls not at altitude but at maximum pressure — that is, at sea level or below. To reverse the sign of the difference and begin to inflate the capsule outward, one would have to climb to where the outside pressure fell below the internal ≈50 hPa — and that is already beyond 60,000–67,000 ft, far outside ordinary flight.

Damage to the Transmission

Old aneroids show two principal transmission architectures. The first is lever-based: from the capsule runs a main lever, then an angled (bell-crank) lever on pivots, and beyond that there often stands a fusee chain on the needle's arbor. The fusee chain resembles a microscopic clock chain: convenient for large magnification and smooth motion, but no lover of jolts and misalignment.



An early Lucien Vidie movement with an external coil spring.

A conventional movement with a C-spring.

A fusee chain.

The second is the toothed type: a sector or rack works with a small pinion; such a scheme looks sturdier, but its teeth are small, and the axes and mesh are designed for the normal working range, not for an aeronautical experiment.

A rack-and-pinion movement with an internal coil spring in the capsule.

Now imagine the climb. The pressure falls, the capsule changes shape, the needle or pen runs towards the lower edge of the scale. At some point the indicator comes up against its stop, and the mechanism reaches the end of its geometry. But the capsule still "hears" the pressure and keeps striving towards a new position. The result is an unpleasant scene: the sensing element pushes while the transmission is already jammed. Any further change in pressure loads not a freely moving mechanism but a clamped system. Then the thin levers bend, the chain slips off or breaks, the pivots are crushed, the teeth of the sector or pinion are chipped. The reaction from the stop does not vanish — it returns into the drive link and into the thin face of the capsule, into the very place where the designer counted only on small elastic displacements.

The Sprung Capsule: Over-Stretched Past the Elastic Limit

If the capsule is highly evacuated, the internal pressure is small and the main load is set by the difference $\Delta P = P_{out} - P_{in}$. At the ground the external pressure compresses the capsule; the external or internal spring opposes that compression and sets the working position. During the climb the external pressure falls — that is, the atmospheric force compressing the capsule diminishes. Here is where the risk of the sprung design appears. The spring was designed for equilibrium with atmospheric pressure within the working range; when the outside pressure falls below the scale, the spring keeps its force by the law of elasticity, while the opposing force of the atmosphere decreases, and the equilibrium position shifts towards stretching the capsule. If the transmission allows no free travel, or if the spring itself pulls the walls beyond the permissible working deflection, the thin metal passes from reversible elastic deformation into permanent plastic deformation.

The physics of the failure here is the usual one for elastic pressure elements. At small stresses the metal works elastically: after unloading, the form returns. Above the elastic limit a permanent set appears; under repeated cycles and at local stress concentrators, fatigue damage arises; the corrugations and soldered seams are especially vulnerable, because there the gradients of curvature, the manufacturing stresses, and the inhomogeneity of the material are all greatest. For a barometric capsule this shows up as a zero shift, non-linearity of the scale, increased hysteresis, and, in the limit, a crack or a leak along the seam. A leak through the seam kills the very principle of the aneroid: pressure appears inside, and the sensitivity falls or disappears. The cold aggravates the problem not by magic but in a dully engineering way — it alters the elastic modulus, the viscosity of lubricants, the clearances, and the brittleness of contaminants; old lacquer, dust, and thickened grease can turn a smooth motion into a jump.

The Capsule with Residual Gas: Boyle–Mariotte in Miniature

Temperature compensation of an aneroid could be carried out in two ways: by changing the amount of residual gas in the capsule, or by introducing a bimetallic link into the transmission. Residual gas is needed because, on heating, the pressure of the gas inside rises and can partly compensate for the temperature-induced change in the elasticity of the metal and springs; this is the classic method of compensation at a given pressure level. If a noticeable amount of residual air is left in the capsule, a climb in an aircraft creates a situation qualitatively like the bag of crisps. As the external pressure decreases, the internal gas expands the capsule to a new equilibrium; if the process is close to isothermal, the pressure and volume of the gas are related by the Boyle–Mariotte law: $P_1V_1 = P_2V_2$. But the difference from the bag is fundamental: the capsule is metal, corrugated, has a finite elastic limit, a soldered seam, a connection to a lever, and often an opposing spring. Damage here is therefore likelier not as a simple "inflating of a soft bag" but as an exceeding of the permissible deformation of the thin diaphragm or seam. In the theory of elastic sensing elements the working travel of the diaphragm must remain within the region of elastic deformation; going beyond it gives a residual deflection, a zero shift, and increased hysteresis. It is for this reason that the WMO specifies a permissible hysteresis after a pressure change of 50 hPa: for a precise aneroid, a return to the former pressure must not leave a noticeably different reading.

The Self-Elastic Capsule: The Risk Lies in the Travel, Not the Pressure

The self-elastic capsule differs in that the restoring force is created not by an external or internal spring but by the corrugated metal of the capsule itself. If such a capsule has residual air left in it for compensation, the high-altitude picture is again close to the bag of crisps: as the external pressure falls, the internal gas seeks to increase the capsule's volume, while the metal resists as an elastic shell. With a sufficiently large travel the same consequences are possible: residual deflection, hysteresis, fatigue accumulation of damage, and loss of tightness.

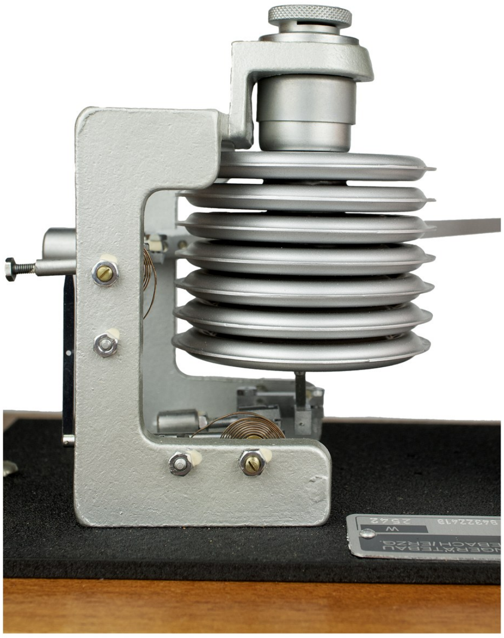
If, however, the self-elastic capsule is nearly evacuated, the analysis is different. Since P_{in} is small, a decrease in P_{out} reduces the compressive load on the capsule; of itself it strives not towards further compression but towards its freer form. In this case low pressure as such is less dangerous to the free capsule than to one with gas or a spring: there is no internal gas to expand the volume greatly, and no separate spring left "over-stretched" when the atmospheric counter-pressure vanishes. And yet the free capsule is a laboratory abstraction: in the instrument it is connected to the transmission. If the mechanism has reached its stop, the self-elastic capsule cannot take up its free form, and the reaction from the stop returns into the drive link and the thin wall. For a nearly evacuated self-elastic capsule, therefore, the chief high-altitude risk is not the reduction of atmospheric pressure itself but the limited travel of the mechanism, the local load at the point of attachment, and the subsequent residual deformation or leak.

The Barograph: A Stack of Capsules and the Vulnerability of the Pen

A barograph is the same aneroid, but instead of a needle over a dial a pen traces on a paper chart wrapped around a drum that a clockwork turns once a day or once a week. The barograph therefore inherits all the risks of the aneroid and adds its own. A single capsule's travel is too small to drive a long pen directly, so the capsules are often assembled into a stack (5, 7, or more) along a common axis — "in series," each adding its travel to the total. The stack can be arranged in two ways: each capsule sealed separately, or all the elements communicating with a common evacuated volume. The difference shows up on failure: with separate capsules a leak in one cell reduces only that cell's contribution, whereas with a common vacuum a leak can put the whole stack out of action at once. But the stack has a reverse side at altitude: the total parasitic travel also adds up — the stack opens by the sum of all the capsules, and the overload is passed on down the chain amplified.

A barograph with a stack of individual capsules.

Marine instruments and some precision barographs sometimes use a single bellows construction with an internal spring, and may also have damping, including oil damping. The oil helps to quiet the roll and vibration, but in the cold it changes viscosity, and under changes of pressure and temperature it can behave unpleasantly for the sealed or semi-sealed assemblies. If the damper is old, with an unknown oil and micro-leaks, air transport adds three trials to it at once: pressure, cold, and vibration.



The bellows of a marine barograph.

The pen arm is the longest and most delicate element of the whole barograph kinematics, and its travel is rigidly fixed by the width of the drum. In normal weather this is a virtue: the trace is large, legible, handsome. At altitude it is a defect: the opened stack drives the pen beyond the upper edge of the chart, into the stop. The pen quickly reaches the edge of the paper or a mechanical limit, while the aneroid stack still strives to move — and the thin arm begins to bend, to deform, and to drag along with it the rest of the kinematics, which is already at the limit of its range. Hence the old rule: before air transport, the pen arm is detached.

The Bourdon Barometer: A Tubular Spring Under Vacuum

The sensing element in Bourdon barometers is a tube bent along a circular arc, with an elliptical cross-section symmetrical about its principal axes — in essence a tubular spring. The major axis of the cross-section is perpendicular to the radius of curvature. Such a spring deforms when the difference between internal and external pressure changes — in barometers specifically it changes its curvature in response to changes in atmospheric pressure. The tube's inner cavity is sealed and held at a pressure close to vacuum. When the atmospheric pressure rises, the ends of the tube come together; when it falls, they move apart — the tube tends to straighten.

The movement of a Bourdon barometer.

The transmission is characteristic: a flattened, crescent-shaped vacuum tube, a fan-shaped toothed rack, and a pair of levers — that is, twin lever → sector rack → pinion, with a hairspring to take up the play. The magnification is, as a rule, more modest than in the capsule instruments: the tube gives a larger travel of its own free end, and a long multiplying cascade is not needed.

At altitude the same logic applies as for the self-elastic capsule. At the ground the atmosphere (760 mm / 1013 hPa) compresses the vacuum tube most strongly and coils the crescent most tightly. During the climb the outside pressure falls (in a pressurised cabin to 563 mm / 750 hPa), the "outside minus inside" difference decreases — and the tube uncoils towards its free, unloaded form. Of itself the tube is not damaged by low pressure in the ordinary range; the reversal of sign (when the outside falls below the residual vacuum within) would come only at altitudes beyond ordinary flight.

The danger, then, is where it is for the aneroid — in the jamming of the transmission. The needle lies against its stop at the lower edge of the scale (711 mm / 950 hPa), while the tube keeps uncoiling: the pressure falls further, towards 563 mm and below. The fan rack comes up against its limit, and the reaction bends the thin paired levers, chips or skips the teeth of the sector, over-stretches the hairspring. The rack is an elegant part and not the sturdiest; it takes this harder than the coarse capsule kinematics. The reaction of the jammed transmission arrives precisely at the point where the free end is attached, and at the soldered joint; crush it, and the tube loses its vacuum. Bourdon barometers, even without any aviation, have a reputation for being prone to loss of rarefaction and to drift — a high-altitude overload merely finishes off an already elderly seam. A thin tube bent past its elastic limit (by the reaction of the jammed rack, or — in the exotic case of a sign reversal at extreme altitude — by reverse straightening) takes on a new resting form, and the zero drifts. The hysteresis of a Bourdon element is appreciable even under normal conditions, so that even without visible plasticity a hard excursion leaves a residual offset.

Altimeters and Altigraphs: The Instruments That Are the Exception

Working with historical instruments, one gradually comes to see them not as a set of brass parts and thin springs but as a kind of witness to their age. Many of them have outlived changes of state, wars, sea voyages, and decades of daily service. It is therefore especially ironic to realise that a serious threat to them today may come not from age at all but from a few hours' flight in a modern aircraft — a technology that appeared decades after these instruments were made.

There exists, however, a whole class of aneroids for which altitude is not an emergency regime but a normal habitat. With them the rules are reversed, and this is precisely the case where what is interesting is not the breakage but its absence.

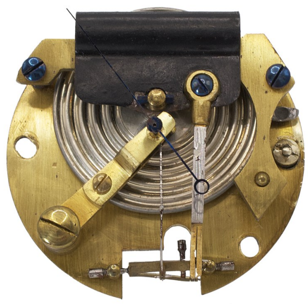
A Thommen altimeter with a 6,000 m scale limit.

The cause of their robustness is not any special strength but geometry. In an altimeter the travel of the transmission and the stops are designed for the whole range of low pressures right up to its ceiling; the capsule (or stack of capsules) and the spring work within the elastic limit not up to 711 mm but up to the values corresponding to the instrument's ceiling. The needle at 8,000 m does not rest at an extreme position — that is its lawful, normal position, if the instrument is rated for ten thousand metres or more. And the reserve is often laid in beyond the readable scale. No jamming — no reaction from a jammed transmission, no over-stretching of the capsule. Aeronautical instruments gain the necessary travel with a stack of capsules and drive it through a sector rack and pinion — as in an aneroid altimeter with evacuated corrugated bronze walls.

This group includes several types of instrument, but more important than the type is the limit of the altitude scale, indicated as a rule right on the dial.

Pocket barometric altimeters (orometric barometers): small aneroids in a brass or nickel-plated case, with a rotating altitude bezel over the barometric scale, temperature-compensated. It should be remembered that the altitude scale may be calibrated in either metres or feet, and this must be taken into account when working out the safe altitude for a given instrument.

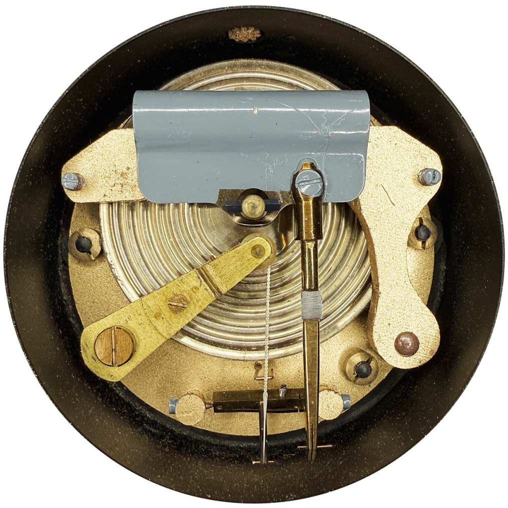
A Keuffel pocket barometer with an altitude scale limit of 3,000 feet.



The Keuffel pocket barometer: the movement.

Levelling and mountain instruments for great heights: mid-sized instruments, often ebonised to protect the case, with a knurled nut on top to work a vernier — for the barometric levelling of terrain. To these belong the Paulin-system altimeters and the Goldschmid aneroids. The rule is the same: the safety of air transport is determined by the range of the altitude scale.

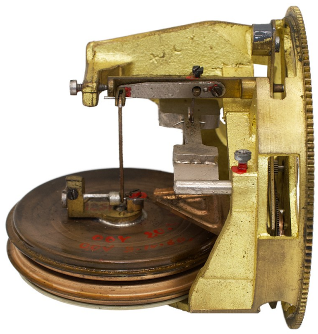
A surveying barometer with an altitude scale limit of 3,000 metres.



The surveying barometer: the movement.

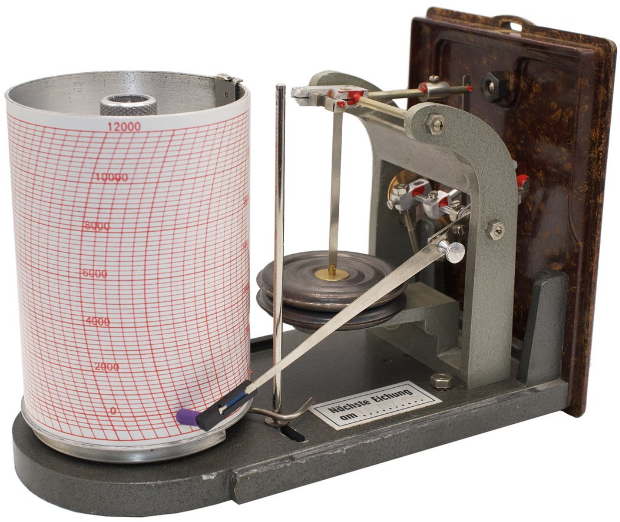
Aircraft altimeters: sensitive multi-needle instruments for the cockpit panels of an aircraft, with a stack of capsules and a sector drive; such instruments have a high ceiling and are safe to carry by air.

A Kollsman aircraft altimeter.



The mechanism of the aircraft altimeter.

Altigraphs (recording barometers): aviation, ballooning, gliding. As a rule these too are safe for air transport, if the range of the scale allows — but the instrument must be prepared, and the arm with the writing pen removed, before transport.



A recording altitude barograph.

Even so, the exception remains a bounded one. It holds only up to the ceiling of the particular instrument — and by survival, not by reading. A pocket altimeter rated to 5,000 ft (about 1,500 m) is, in an ordinary pressurised hold (563 mm / 750 hPa), overloaded as hopelessly as a domestic barometer: the needle against its stop, the mechanism jammed. So "altimeter" does not automatically mean "invulnerable": the low-range survey instruments are, by their effective ceiling, not far removed from the weather instruments.

The practical criterion for this class is reversed. The main question is whether the flight altitude fits within the instrument's ceiling. In any pressurised hold (the equivalent of 2,440 m / 563 mm) any altimeter with a ceiling of 3,000 m and above sits in the middle of its scale — the one class of instrument that really does travel safely by airmail.

There is, however, one reservation shared with the barographs: pressure is no enemy to them, but knocks and shaking are. The pen arm of an altigraph, the pivots, the suspension of the sensing element all fear rough handling regardless of altitude. Hence the final paradox: the only instruments to which airmail holds no terror are those built to measure altitude itself. The barometer that maps the trap turns out to be the very one that passes through it unharmed.

Conclusion

The airmailing of an aneroid barometer or a barograph is not merely transport but an uncontrolled trial by pressure, temperature, vibration, and the stops of the mechanism. The practical conclusion is a hard one: antique and vintage aneroid barometers and barographs — including precise meteorological aneroids as collector's items — should be sent by surface transport. If air carriage is unavoidable, the instrument should be assessed by a specialist, the mechanism unloaded or locked in a manner reversible for that particular model, and after transport a check of the zero, the hysteresis, and the tightness is required.

This, perhaps, is what strikes me as the most surprising conclusion of the whole story. We are used to thinking of aviation as the safest and most careful way to deliver valuable things, yet for an old aneroid it turns out to be an environment to which it was never adapted. The deeper one goes into the history of scientific instruments, the clearer it becomes that caring for their survival requires a knowledge not only of history but of physics, of engineering, and even of the peculiarities of modern logistics. Sometimes the fate of a century-and-a-half-old instrument is decided not by the rarity of the model or the skill of the restorer, but by the understanding of one simple thing: at a height of a few kilometres, the atmosphere becomes something quite different.

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