Hyperloop, The Steampunk 19th Century Version

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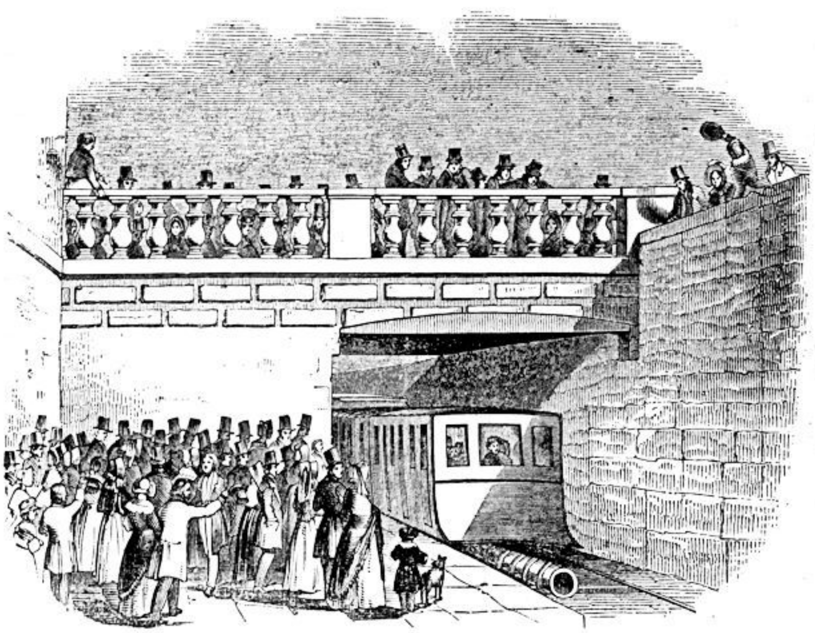


A view of the departure of the Atmospheric Railway train at Dalkey, Ireland. (From [The Illustrated London News of Jan. 6, 1844](#))

Some time ago, a new form of transportation was invented. It was fast, it was clean, it was quiet, it made use of vacuum in tubes, and it generated great excitement – even mania.

Hyperloop? No, these were the Atmospheric Railways of the mid-19th century. It's not well-known today that four such railway lines were built and carried hundreds of thousands of passengers between 1844 and 1860.

In many ways, Atmospheric Railways were the hyperloop of that time. They have an interesting and instructive story, told in the 1968 book "Atmospheric Railways, A Victorian Venture in Silent Speed" by Charles Hadfield. Although this technology did not last, and *because* it did not last, there are important lessons for hyperloop and other forms of innovative transportation today.

The Technology

The concept is simply pneumatic tube travel. Not like the Jetsons, but rather using vacuum and air pressure to move railway carriages along their track at high speeds. Some articles trace hyperloop ancestry to the short experiments in a tunnel under Crystal Palace Park in London (1864) and under Broadway in New York City by Beach Pneumatic Transit (1869-1870). But the roots go deeper. Those two were demonstrations, with a railway carriage inside a tunnel (like a hyperloop tube) directly pushed by air pressure from giant fans more than 6.5 m in diameter or pulled by the vacuum created by such fans. Both were inspired by the earlier Atmospheric Railway, which was much more of a success. Atmospheric railways used a tube, typically with diameter between 15 and 25 inches (about 40 to 60 cm), with a piston inside that was moved by differential atmospheric pressure. The piston was connected to the train outside the tube through a valve running the length of the tube. The valve allowed a physical connection but minimized air leakage as the connecting rod traveled along the tube. The vacuum was generated by large engines spaced along the line.

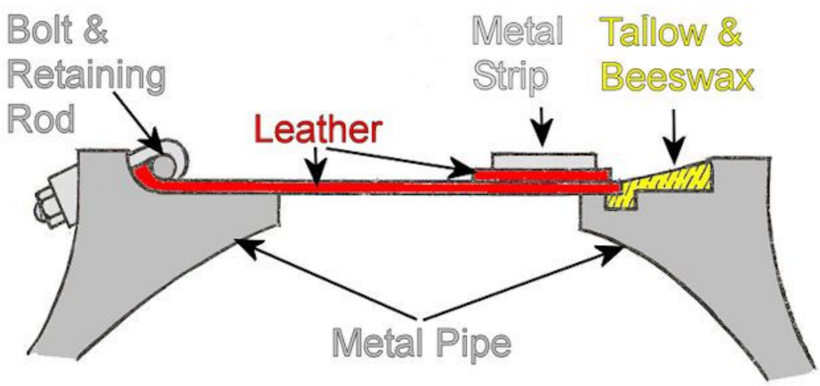
One of the larger, 22-inch diameter tubes, with the slot visible at top. The slot was covered with a leather and metal valve and a sealing compound. A mechanism passed through the valve connecting the piston in the tube to the train above. (Photo courtesy William M. Connolley at the English language Wikipedia)

This configuration had some big advantages over the coal-driven steam locomotives of that era.

- There was no smoke and smell moving along with the train – an advantage for both passengers and the neighborhoods the train passed through. The stationary engine houses did generate smoke, but these were located away from dense populations.
- Unlike locomotives, these trains were very quiet, with just the rush of wind. This too was appreciated by passengers although there were a few collisions with people standing on the tracks that did not hear the train's approach. (Today's hybrid and electric cars produced a similar problem; they now emit an artificial sound to warn pedestrians).
- The train is much lighter because the engine is stationary rather than part of the mass that must be moved. This makes Atmospheric trains, at least in theory, more efficient to operate. The same principle applies to today's electric trains powered through a third rail.

- In testing, the Atmospheric Railway achieved speeds greater than 70 mph, although this was not done with lines in service
- Perhaps the largest advantage was that atmospherically-driven trains could navigate much steeper routes than locomotives. Even with great power, locomotives would lose traction going up gradients steeper than about 1:100 (about 0.5-degree incline). Atmospheric Railways being pushed or pulled by a piston didn't rely on traction, so their climbing ability was limited only by the available power and weight of the train. They could run on grades more than twice as steep as locomotives. This promised to enable routes that were more direct, with less tunneling or cuts at the top of hills and so cheaper to construct.

The main technical disadvantage, as you might guess, was that an effective valve mechanism was hard to design and maintain with the machinery of the time. Many ideas and patents addressed this, and some solutions worked well if properly maintained.



Atmospheric Railway valve, based on the original drawing by Joseph Samuda, November 1846 (figure permission, Epsom and Ewell History Explorer)

Atmospheric Railway lines put into service

Dozens of Atmospheric Railway lines were proposed in the 1840s, with investment funds raised and applications made for government permissions and rights-of-way. Four were ultimately built and put into service.

In Ireland, the Dublin and Kingstown Railway operated a line from Kingstown to Dalkey between 1844 and 1854. It was just short of 3 km long, and although not trouble free (nor were locomotives) it was successful, well liked, and well used by many thousands of commuters. An interesting takeaway from Hadfield's book is that the line spurred residential growth near Dalkey. Economic development enabled by good transportation is part of the modern story of the Shinkansen high speed rail operating in Japan since the 1970s. The same should be expected around hyperloop lines. As Hadfield tells the story, the demise of this line after 11 years of use was due to the train company's desire to convert the track to the wider gauge typical in Ireland. Although there were many problems (and much learning) during its use, neither the technology nor economics was responsible for its end.

Near London, a line was operated from 1846 to 1847 by the London and Croydon Railway. It was about 8 km long with a total of 5 stations and 3 pump-engine stations. The approval and construction for this line took many years, and it had more than its share of operational delays from equipment failures and unforeseen problems. For example, at times there was not sufficient water to run one of the pump stations that created the vacuum. In addition to financial failures such as unexpected costs and a loss of investor confidence, the system failed on a technical level. It didn't produce enough power for the heavier, longer trains that were needed.

It seems ridership demand quickly increased well beyond its original design, and the cost of expanding the atmospheric system was considered too high. Expansion would require a larger tube and bigger stationary engines, or possibly construction of a second line. Although its lifetime was short, this line achieved fast, frequent commuter service with 39 trains daily, and passengers enjoyed the clean and quiet ride.

Another line in England was operated by the South Devon Company between 1847 and 1848, so it too had a fairly short working period. This line went about 24 km from Exeter St. Davids to Teignmouth with a total of 5 stations and 6 stationary engine house locations. It was later extended to Newton, about 32 km total and with 2 more engine houses. The line was in a hilly part of southwest England, making it well suited to atmospheric propulsion. Although the South Devon line suffered from some engineering design limitations and higher than expected operating costs, the system ran well for the first few months. It typically made 11 trips each day, so passengers enjoyed the quiet, smooth, and smoke-free ride for more than 1000 runs.

But the route (and its investors) suffered from unexpected costs because of needed changes to the tube size, extra coal and engine wear-and-tear because of poor communication, and especially from failures in the valve system. Telegraph communication, new at the time, was important to let engine operators know when to turn on the vacuum pumps. If a train was delayed and the engine ran longer than needed, it increased the cost of coal and worsened the engine wear. Several valve types were used on Atmospheric Railways, generally with some configuration of strips of leather, metal plates, and a sealing compound. The leather on the South Devon line suffered first from cold weather and later from very dry weather. Replacement was costly, and with a poor vacuum seal, the pump engines had to work harder and longer. There were also problems with broken engine parts, some of which were made of cast iron but should have been made of stronger wrought iron.

The atmospheric propulsion for this route ended when it was decided that, although a successful Atmospheric Railway line was possible, fixing this one would mean nearly starting over with new equipment. Ultimately, it was a lack of design and systems engineering experience that led to the short life of this line. The cost of the learning curve was too high, and the line was switched to locomotives.

The fourth working Atmospheric Railway line operated in France between Bois de Vesinet and Saint Germain. This was a line about 2 km long that extended from the terminus of a locomotive-driven line arriving from Paris, up to the town of Saint Germain. The grade to the town was too steep for a locomotive. This line operated from 1847 until 1860, making it the longest running of the four. It was very successful and relatively trouble-free. Service ended only when more powerful locomotives were able to navigate the hill. With these locomotives, passengers did not need to change trains to continue on to Paris.

After these four experiences, the railway industry and investors moved on from Atmospheric technology. The experience did lead to the Crystal Palace and Beach Railway experiments, and also to the small pneumatic tubes still used today at bank drive-up tellers. The Atmospheric Railway concept did emerge again, but not for another 100 years (see the postscript to this article).

Stationary engine house at Totnes on the South Devon line (Photo from 2007 by Geof Sheppard, Wikimedia Commons)

<u>What can the Hyperloop industry learn from the Atmospheric Railway Experience?</u>

There is much detail in Hadfield's book and it is well worth reading if you can find a copy. Lessons from this experience could apply to the current state of hyperloop:

- Set and meet clear expectations when communicating with the public, investors, and policymakers. Builders of the Atmospheric Railway found it was harder than expected to get from the ideal – on paper – system to a working and maintainable operating railway line. They made claims to their investors that seemed naïve in hindsight, both underestimating costs and being overly optimistic about timeline, performance and maintenance. As Hadfield describes, there was a "mania" about the concept during its early years, but after setbacks with the Dalkey line, the mania peaked and quickly turned to disappointment. He writes "…people realized how young and untried the new principle still was, and how many practical problems still had to be solved. These things were enough to swing the national mood from extreme optimism to a pessimism and cynicism." New investment and government approvals for all Atmospheric Railway proposals never recovered from this shift in sentiment. In the current hyperloop endeavor there is a great deal of promise and excitement. There is also relatively little publicly demonstrated capability and no record of reliability. Following a step-by-step development process, providing open progress updates, and creating a culture that is realistic about cost, schedule, and performance would give investors and enthusiasts confidence. Otherwise, the creators of hyperloop could generate a level of expectation and excitement that eventually gives way to disappointment and disillusionment.

- Be open with information. Atmospheric Railway engineering reports to shareholders were filled with the bias of those gathering the information, as were newspaper reports. There were even "spies" who rode the working lines and recorded all delays or mishaps. These spies even estimated ridership, coal use, and other factors to make independent estimates of operation and maintenance costs. Discrepancies between the engineers' estimates and these independent assessments also reduced shareholder and public confidence.

- Be realistic in expecting an iterative learning curve. Experienced system engineers and program managers know that new technology development requires iterative testing and adjustment. Some points of failure can only be discovered through long-term experience. The Atmospheric Railway lines did a great deal of testing before opening to the public, but they did not plan for revisions and upgrades in the early years of operation. This frustrated shareholders (and board members) who were promised an early profit on their investment. There were also examples of engineers greatly revising plans or setting new requirements even as a line was being built. Sometimes this led to compromised performance, such as pump engines and tubes that were not optimized to work well together.

- The network effect is a key requirement for success. Early Atmospheric Railway lines were built with the expectation they would be extended, and eventually most railways would use the technology. But early difficulties led to companies delaying or cancelling extensions, and instead building them for locomotives. Shareholders understood how new lines would increase the ridership of existing ones, and the need for passengers to change back and forth between locomotive driven and atmospheric drive segments was a disincentive and a factor in their demise. Hyperloop is a huge opportunity, and would benefit from many interconnected routes operating seamlessly for consumers. Success for the industry is more likely if there is strong cooperation among technology developers to speed adoption of many compatible routes.

- Understand who the gatekeepers are. Based on Hadfield's book, the decision-makers were the investors and the government (Parliament in the U.K.). Investors were concerned about their financial gains or losses. The public preference for clean and quiet rides was only a small factor in choices to extend or cancel routes. The Atmospheric Railroad project leaders failed to maintain the confidence of their most important stakeholders.

- Gaining government permissions was a huge challenge for the Atmospheric Railway lines. In the U.K. each new line needed their "Act" to pass Parliament. Competing railway lines naturally opposed more competition and lobbied against many Atmospheric Railway lines. Hyperloop has already found that this has not fundamentally changed - government approvals and regulation remain a huge challenge.

Postscript

More than 100 years later, the Atmospheric Railway concept emerged again. A Brazilian company is currently using modern designs, yet is creating a transportation system very similar to the Atmospheric Railways of the 19th century. Aeromovel uses pressurized air to push a propulsion plate through a duct within a guideway. The plate is attached to a train and propels it forward along an elevated track. In 1989, following prototypes and tests in the 1970s and 1980s, a 3.2 km loop Aeromovel railway opened in Jakarta, Indonesia, and remains in operation to this day nearly 30 years later. A second Aeromovel system, connecting the metro and airport in Porto Alegre, Brazil, has operated for public use since 2013. These lines have a maximum speed of about 65 km/h and have carried many millions of passengers. According to operators, they have also been low maintenance. Another company, FlightRail based in California, USA, has built a prototype (1/6 scale) atmospheric railroad operating on a 0.6 km loop test track.

It uses a magnetic connection between the piston inside the tube and the train above, eliminating the technical complexity of a valve. These modern implementations claim advantages of simplicity and reliability, low costs because of low weight vehicles that do not carry an onboard motor or engine, and better ability to climb grades and make tight turns than traditional light-rail. Although this technology appears to offer some clear advantages, its use as a form of public transit has not so far moved beyond the two Aeromovel implementations.

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