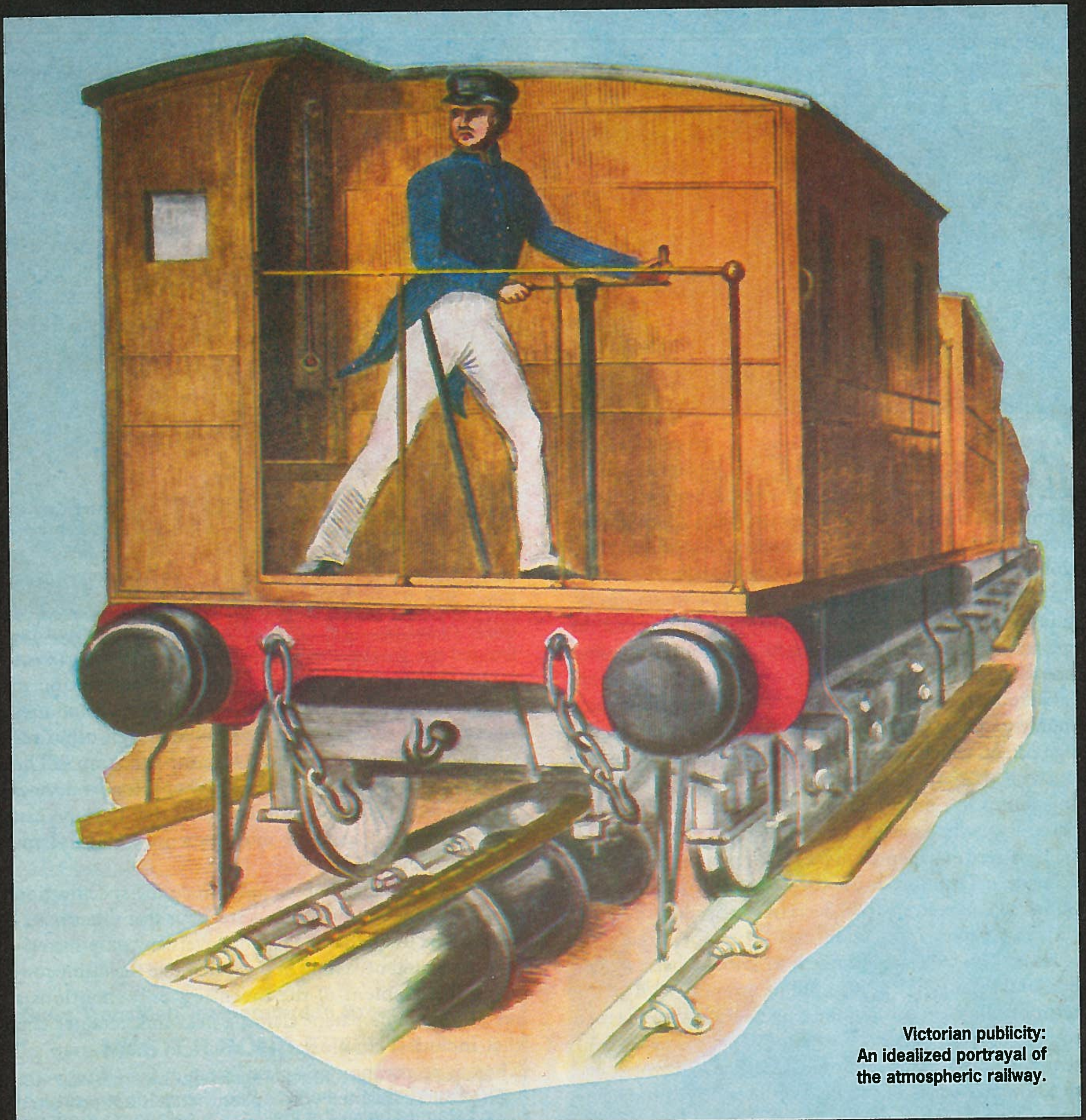


Victorian publicity: An idealized portrayal of the atmospheric railway.

Tally-Ho the Vacuum

An idea whose time had not quite come. By Robert O. Woods

Victor Hugo coined the phrase, "The power of an idea whose time has come." The world has seen many ideas that were powerful, some earthshaking, some technological—democracy, the scientific method, the airplane, the Internet—but there have been other ideas that looked attractive but failed because of poor timing. The so-called "atmospheric railway," a 19th-century attempt by British engineers to improve rail technology with the use of an evacuated tube, was such a failure.

The middle of the 19th century was a great age for engineering. The steam engine had allowed a growing network of rails to tie together a previously fragmented island, so Britain as a whole was very optimistic about rail technology.

Engineers who built the railroads, however, were aware of the limitations. The public distaste for smoke-belching locomotives could be surmounted, but mechanical constraints demanded something more than a publicity campaign. One factor that nothing could improve was the coefficient of friction of metal wheels on metal tracks. It limited traction and put a ceiling of about one percent on the maximum grade that a conventional locomotive could negotiate. That greatly constrained railbeds in hilly terrain.

The "atmospheric" railway was conceived as a solution to both problems—public relations as well as mechanical. Coal-burning pumping stations could be located away from urban centers and the prime mover did not depend on the traction of wheels on track. Even now, we cannot say that it was a fundamentally bad idea. During its heyday in Britain, from about 1843 to 1848, there were a dozen or more separate lines.

The Industrial Revolution began in Newcastle in 1710 with the Newcomen steam engine, which depended on vacuum rather than high pressure. That may have made Victorian engineers particularly conscious of vacuum-operated machines.

The atmospheric railway depended on vacuum. It was a system very much like the pneumatic conveyors that were common everywhere until recent years. The heart of the system was an evacuated tube about a foot in diameter. It was located between the tracks and stretched the entire length of the road. A piston driven by atmospheric pressure moved inside the tube and was connected to the train by a strut running through a groove in the top of the tube.

An elaborate zipper-like arrangement kept the tube sealed on the vacuum side ahead of the piston, and open for several feet behind it to allow air to enter. It is not intuitively obvious that this arrangement can generate a respectable tractive force until one does the arithmetic. A 15-inch-diameter tube, for example, evacuated to about half an atmosphere provides force on the order of 1,300 pounds, which is quite adequate to move a small train.

The atmospheric railway is documented in exhaustive detail in *Atmospheric Railways* by C. Hadfield (David and Charles, Newton Abbot, 1967). This book not only gives technical information, but also explores the cultural anthropology that went into arranging funding and wooing public support. The British government's involvement strongly resembled the politics now connected with the International Space Station. And as with NASA, railway developers had to solicit public support for their efforts.

Press releases were planted in the newspapers to arouse public interest. An image used in the campaign was of a heroic figure at the front of a carriage. It represented a driver of the train who manipulated a valve and a brake. There was no other onboard machinery.

The effort to secure the public's approval involved gestures beyond spirited press releases. Britain was in the middle of the Gothic architectural revival and pumping stations were designed according to the rage. Many of the stations resembled a bad stage setting for *Ivanhoe*.

Experimentation with the "atmospheric" system began in earnest in 1840 and led to successful passenger-carrying in 1843. The initial work was done in Ireland at Dalkey.

The success in Ireland attracted the attention of Isambard Kingdom Brunel, who had spearheaded the construction of the Great Western Railway a decade before. He became involved with the "atmospheric" concept in 1844, in the middle of a career that had begun in 1825, when he supervised construction of the Thames subway tunnel at the age of 18.

Brunel initially toyed with the idea of producing a vacuum without mechanical pumps, using Newcomen's method of filling shells with low-pressure steam to displace the air, then condensing the steam with water injection to create a vacuum. Ultimately, more conventional pumps driven by steam engines were chosen. The very first versions were walking beam types in which reciprocating engine and pump cylinders were connected side by side with a pivoted beam, in an arrangement like that used to pump water from mines. A more familiar arrangement using rotating machinery was soon adopted.

The 82½-horsepower engines had flywheels 25 feet in diameter with connecting rods 20 feet long. The steam cylinders were 40 inches in diameter and the pump cylinders 80 inches. The pistons had a stroke of 8 feet. They did not have piston rings, which were invented 10 years too late.

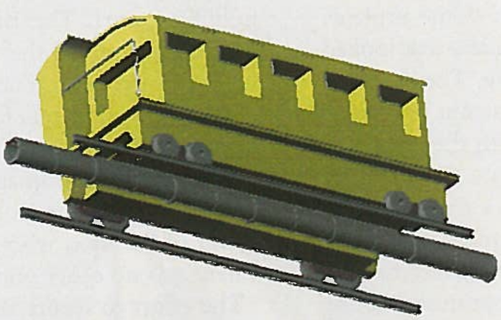
A very sophisticated valve cycling and timing arrangement was incorporated, however. The entire design may well have been analyzed using the work of Carnot, who had published the cycle that bears his name in 1825, just a few years before. The ability to treat a heat engine mathematically was one piece of the puzzle that did arrive in time to be useful.

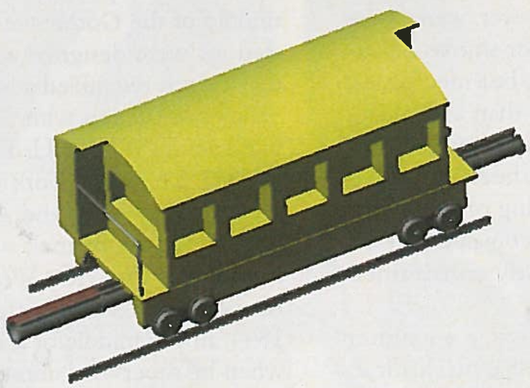
Iron casting had become a fine art by the time of the atmospheric railway. Since wrought iron was more expensive than cast iron, bridges and large structures, such as the famous railway stations designed by Brunel, were being made increasingly of cast iron. A decade later, this technology was raised to a high point in the United States,

Robert Woods is a Fellow of ASME and a frequent contributor to *Mechanical Engineering*. Although it was some years ago that he visited the sites of Brunel's triumphs in Britain, he only recently learned of the atmospheric railway. It is not advertised as one of Brunel's big successes.

where the dome of the U.S. Capitol was made of cast iron.

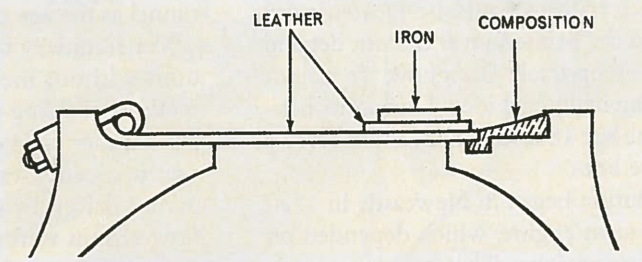
The tubes for the atmospheric railway were cast iron, delivered in nine-foot lengths and bolted together. A large valve at each station isolated the approximately three miles of line being served by each pump. Synchronizing the operation of valves and pumps with train motion was critical. A first generation of telegraphy was available to coordinate the timing over distances, but although it was being used successfully on other lines, Brunel appears not to have trusted it and relied instead on a printed schedule. That was very inefficient, resulting in the pumps running when they were not needed.





The key to the overall operation was a means of sealing the longitudinal gap in the tube while allowing a strut to pass through. This arrangement is conceptually similar to the one used today to catapult shipborne aircraft. It posed a major challenge to Victorian-era engineers.

Even with the technology now available, there is still substantial leakage in shipboard catapults, which operate with pressure instead of vacuum. In modern equipment the steam generators can be sized to overwhelm any predictable leakage. The Victorian engineers didn't have the advantage of brute force and fought a losing battle to seal their system.



The railway relied on a vacuum tube beneath coaches. The method of sealing the system proved to be one of the weak points of the scheme.

Lubrication of the sliding seals and choice of materials were questions to which the answers also arrived a few years too late. The vulcanization process for rubber was discovered at exactly the same time that experimentation on the atmospheric railway began in 1840.

Since rubber was not initially available as a choice for flexible seal components, the only alternative was leather. That led to some bizarre-looking arrangements in which the slots were sealed by leather flaps, which were raised locally as the strut passed through them. An elaborate arrangement was contrived to hold open roughly a 15-foot length of the valve behind the piston, allowing air to enter and provide the necessary pressure differential. Force to reseal the gasket was accomplished by a following set of wheels that pressed the leather valve into a sealing matrix of beeswax and tallow. To render the seal more pliable, a heater filled with smoldering charcoal sometimes followed.

The seal, which involved a series of leather flaps that had to be opened in succession, was a qualified success. Later, an engineer named Hallett proposed a geometry shaped much like that now used on aircraft carriers. It had a plate running between two inflated rubber tubes that ran the entire length of the system. That substituted a continuous slide for a domino-like progression. It probably would have worked, but by the time it was proposed, the atmospheric railroad was already doomed

As much of a handicap as the primitive seal material was the state of lubrication. Oil, which would have been useful, first became commercially available from wells in Pennsylvania in 1859, just as the final branch of the last line closed. Grease, made by bulking oil with additives to make it more viscous, and the ubiquitous grease cup, were not to be invented for another decade.

Victorian engineers were limited to the millennia-old choices of animal fat and tallow, which, along with the properties of leather, proved to be a real problem. In addition to being short-lived, thus requiring an ongoing expenditure of manpower to apply lubricant over the length of the line, the leather/animal fat combination was prone to freezing in winter and the leather to fatigue failure even at room temperature. Beyond that, a problem today's tribologist does not often face was that of rats eating the gaskets. In the case of one line, the 20-mile South Devon, replacing the gaskets cost 1,018 pounds. That may well have been the final nail in the coffin of that particular run, which had initially cost on the order of 43,400 pounds. To put this in perspective, a well-paid executive of the time was paid 300 pounds per year.

Charles Fort, a 1920s newspaperman and a keen observer of human history, noted that when the time has come to "steam engine," the human race will "steam engine." That was a whimsical way of saying that when all of the technology exists, it is inevitable that somebody—almost anybody—will put the pieces together and bring on a new epoch. The unstated corollary is that if less than all of the technology exists, some humans can waste a lot of effort and accomplish nothing lasting. The atmospheric railway was not a success and it cost a lot of people a great deal, both in money and in reputation. It failed because there were pieces missing. Ironically, all of those pieces arrived just a few years later. ■

3-D MODELS BY ROBERT O. WOODS