In 2004 the New Yorkers celebrate the centennial of their subway system. But according to the popular believe the first underground railroad in that city was built some 30 years before. In February 1870, after several months of clandestine work, a short section of pneumatically operated underground railroad beneath Broadway was opened to the public. The ultimate responsibility for it belonged to Alfred Ely Beach, the editor of Scientific American and skilled inventor of many-sided interests. His outstanding contribution in promoting pneumatic locomotion in the United States is commonly known and appreciated but he was not the first neither the last American, who spent his time, ingenuity and sometimes fortune for this idea.

NOTHING NEW UNDER THE SUN

The interest in pneumatic transportation dates back to the beginning of 19th century. An English mechanic George Medhurst is believed to be an originator of the idea. He suggested a pneumatic tube for dispatching parcels or letters as early as in 1810. Two years later he extended his proposal on a much more fragile load – the passengers. He proposed two major modifications in this system of transportation. The first method involved a current of air rushing through a tunnel and pushing a passenger wagon. Anticipating passengers' aversion of traveling along an opaque, permanently dark tunnel, Medhurst thought about employing a piston moving within a small tube and dragging a vehicle running on ordinary rails. Although Medhurst thought about employing compressed air to propel the load, his imitators preferred to use vacuum, and thus the method became known as the atmospheric system as an analogy of the early steam engines. In such as engine the piston was being pressed by the atmosphere pressure when the vacuum or partial vacuum was created on the
other side. Contrary the pneumatic systems employed the over-pressure instead of vacuum. However the distinction was not clear from the earliest years of the idea. Many of nineteenth century authors seemed to classify those methods in different manner. By saying 'atmospheric railroad' they meant a system involving a wagon with attached piston-in-pipe notwithstanding whatever vacuum or overpressure was used. In this case the 'pneumatic road' meant described an arrangement, in which a piston-wagon run through a tunnel. It is enough to say that a number of piston-in-pipe systems, commonly called the 'atmospheric', were based on using overpressure alone or vacuum and overpressure acting altogether on the piston for increased power output.

**THE ENGLISH ORIGINS**

Medhurst had never tried the efficiency of his pneumatic dispatch, but few years before his death another English engineer made a trial of a system based on the same principle. It was in 1824 when John Vallance demonstrated a model of it in Brighton. He was running a small passenger carriage inside a wooden tube. He was the very first patentee of air propelled transportation system and even obtained a grant for using it on proposed link between his town and London.

Significantly, the second version of Medhurst's idea, the piston-in-pipe, was practically tested and patented by Henry Pinkus, an American inventor then residing in England. In this system, the propulsion piston, which were deployed in an air duct running parallel to the vehicle guideway tracks, were connected to the carriages by means of arms which must pass through a longitudinal guideway slot fitted with a seal. Depending on whether the overpressure or vacuum was used the seal prevents the escape of air from the tube or admission of atmospheric air. While Medhurst's first imaginary plan was to sink the slit into the channel filled with water, Pinkus though about 'valvular cord', a continuous rope intended to be pressed into the grove formed around the slit. He patented his idea in 1834 and two years later built a short experimental track in London. However the test proved that his system was not workable, it attained the attention of two English engineers, Samuel Clegg and Jacob Samuda. They replaced the cord with flexible flap fastened with iron plates and
eventually their system worked efficiently enough to announce a success and try to put it in operation. In fact four lines of atmospheric railways were built in Europe according to their plans. The first one, somewhat less than 3 km long, was opened in between Kingstown and Dalkey in Ireland in 1844 and worked until 1854. The other ones built in 1846 and 1847 in England worked for about a year each. Finally, the only French line had the longest trial. It was replaced with steam traction in 1860 after fourteen years of operation.

No single mile of atmospheric railroad was built in United States although some attempts were undertaken to do so. The South Carolina Railroad Company intended adopting the system of Clegg and Samuda on proposed experimental line. The company entered the motion to the Senate of the United States to allow the importation of duty free railroad pipes and machinery. They required them for an efficiency test on a one-mile track.\textsuperscript{3} Supporters of that bill stated that all the needed machinery could not be manufactured in the USA. They claimed that it would be 'for the benefit of the local iron manufacturers as well, who would thereby become acquainted with the way of making the pipes in case there should be any further demand for them.'\textsuperscript{4}

The first patents for air driven railway systems in America were granted mainly for English inventors who, anticipating its success, intended to secure their rights overseas. The very first American patent for atmospheric railroad was granted to Samuel Clegg and Jacob Samuda themselves as early as in 1840, that means a year after obtaining their British and French patents.

**TECHNICAL VARIETY**

Among the nineteenth century designs of air powered railway systems four main groups can be found. The principal distinction is the way the pneumatic power supposed to be employed for driving trains. Beside of two methods described by Medhurst, two other were proposed by different inventors. The system involving mechanisms mounted on track and acting the wagons appeared in 1840s as replacement for defective leather flap used by Clegg and Samuda. The last method based on using the pneumatic engines for driving trains was contemplated even earlier. In fact its mode of operation was similar to that of
ordinary locomotives only the compressed air was used instead of steam.

This variety is reflected in the patent classification of the United States Patent and Trademark Office. Different types of those four systems are divided into seven subclasses. Significantly the American classification related to that field of technology is more complex and detailed than any other. For example the arrangement of patents established by German patent office in early 1870s placed the pneumatic systems among hydraulic, balloon and other more or less imaginary alternatives for steam locomotion. In old French classification air propelled railroad systems even were not separated from the main railroad class.

Pneumatic system

The first mode of propelling carriages by air as described by George Medhurst and later developed, was based on tunnels of a diameter sufficient for conveying passenger wagons that were accurately fitted to interior walls of the tunnels. The cars were pushed forward by overpressure behind its backside or by producing vacuum in the front of it and thus letting the atmospheric pressure to act on the train. The attention of inventors was mainly focused on allowing the movement of different trains within the same tunnel at the same. The most significant and widely known contribution in developing and promoting pneumatic tube railroads in America belongs to Alfred Ely Beach, inventor and editor of Scientific American. He was a patentee of numerous improvements in working pneumatic tubes intended both for postal services and passenger traffic. While the other inventors patented sometimes only a fuzzy imagination how their could look like, Alfred Beach obtained few patents for separated components of it such as tube, car, air-blower or station facility. He thoroughly investigated the methods of stopping and starting the trains at the stations. In order to facilitate the stoppage of a piston-wagon and at the same time permitting the driving air-current to flow freely onward through the tunnel, the tube was to be enlarged near the station. In another patent Alfred Beach resolved the problem of the simultaneous movement of the trains in a tunnel. It could be achieved by dividing the tunnel into shorter sections separated with gates. The nature of that invention consisted of an automatic valve operated by approaching piston-
wagon. When a car ran over the lever it opened the valve thereby allowing the car to pass by. When it had passed, gravity caused the valve to fall. Alfred Beach proved the efficiency of his pneumatic system during a show of American institution at the Fourteenth Street Armory in New York City in October 1867. More than 100 thousands people enjoyed riding an open platform through 30 meters wooden tube. Later he bored longer tunnel under Broadway. The dazzling equipped and fine polished underground station impressed the visitors and immediately gained public support for Beach’s plans to extend the route into full-scale subway system. After three or four years of struggle with legal, political and financial obstacles he had to abandon his dream. Significantly, he did not secure any improvement in his system after its trial under Broadway. Did it work good enough to be adopted in full scale from Battery to Central Park as Beach requested for?

At the same time another inventor came with his pneumatic tube as the best solution for transit needs of rapidly growing New York City. A physician Henry Gilbert was interested in the scheme due to his professional experience and particularly his concern about the sanitary conditions in the City. He believed that introducing a clean, cheap, fast and efficient system of mass transit, namely the pneumatic elevated road of his design, could reduce an excessive mortality rate in overcrowded tenement-
houses in Lower Manhattan. In 1870 he secured the mode of construction of a pneumatic tube supported on arches above the street. The patent also included a telegraphic communication system and a pneumatic elevator, which raised and lowered whatever was to be transmitted through the elevated tube. Rufus Gilbert, whose passion of life was architecture, designed an elevated structure with fashionable arcades in Eastlake style that met with enthusiastic reception of the public in 1872, when he formed a company intending to build the first line along 6th Avenue. After several years spent on overwhelming financial obstacles the proposed line was eventually constructed, but far less decorated and equipped with ordinary steam traction.

Among the systems, in which the pneumatic power acts on entire car's body, a number of designs employing spheres or cylinders rolling around its axis were put forward. Generally they were intended for transporting freight. The first to get an American patent for that idea was Elias Needham of New York, a well-known manufacturer or reed organs. Presumably he took advantage of his engineering skills in perfecting air powered music instruments to design an endless tube employing rolling balls in which letters and parcels were to be transmitted. In his system of transportation, a fan simultaneously pumped air out in front of a rolling ball and blew it behind it. It can not be excluded that Needham meant to modify his device to allow the passenger traffic. In fact some eminent engineers emphasized the advantages of his system during the discussion on transit needs of New York City. Later, when Alfred Beach presented his model at the American Institute Fair, some journalists referred to it as the Needham's Pneumatic Railway.

Another inventor who designed a similar device was Albert Brisbane. He was a famous revolutionist and associationist but also an author of several innovative ideas. Brisbane designed a pneumatically operated system for transporting merchandise in hollow spheres and also formed two companies to connect New York with Chicago and with New Orleans. Similar tube was also contemplated for connecting Chicago with New Orleans. The only result of Brisbane's efforts was a contract for a pneumatic dispatch system connecting the Capitol and the Public Printing House in Washington DC. Brisbane obtained a subsidy for this work but due to numerous obstructions failed completing the task. The singularity of another rolling system patented by
Henry Yates in 1873 depended on designing it for carrying passengers. A vehicle, cylindrical in shape and having two large wheels on both sides, was to be placed inside a hollow rim. The body of the car was supposed to retain its center of gravity while the wheels were moving. The car was to be propelled by a current of air rather than overpressure or vacuum, as in previous systems.¹⁴

**Atmospheric system**

This was a system having vehicles that were pneumatically propelled by means of propulsion piston connected to the vehicles. The success of entire scheme was dependent on the airtightness of the flap that sealed the longitudinal slit in the tube. Not surprisingly the question of the efficiency of that sealing was the most important one in the endeavors to perfect the atmospheric railroad systems. In 1840s however, when a substitute for the leather valve of Clegg and Samuda was a subject of investigation of dozens of European inventors, the Americans did not follow them. Only forty years later their attention turned to that idea when more advanced materials and technology were at their disposal, but there was another local feature of American interest in it. While during the ‘Railway Mania’ the engineers in Europe considered atmospheric system as an alternative system for steam locomotion particularly on mountain sections, their American colleagues predominantly designed them for street lines to relieve traffic congestion in large cities. An American of Philadelphia, Christian Goebel, patented one of those late designs.¹⁵ He suggested using sliding metal gates instead of longitudinal flexible seal.

One of the most active American inventors on that field of technology was Thomas Mayall of Boston, a skilled mechanic and inventor of famous machinery gun. According to one of his designs a car was provided with runners and slid over the rails on an elevated track. Thomas Mayall resolved a problem of stopping the train and regulating its speed by means of a wing valve mounted in the piston, something different from the solutions proposed by his predecessors.¹⁶ The novelty of his another project was a suggestion of running the trains on the street level while atmospheric tube was mounted up side down under the arches extending from one side of the street to another.¹⁷
design he proposed to use the sealing made of rubber combined with anti-friction compound also patented by the inventor. In 1887 Mayall published a pamphlet in which he described all of those improvements. Also, he contemplated using two other motive powers, namely the cable towing and electric motors.\textsuperscript{18}

In 1888 Thomas and Anthony Connolly of Washington proposed an ultimate solution, as they thought, for the leakage problem in atmospheric system.\textsuperscript{19} They suggested establishing and maintaining an electromagnetic attraction between a wagon and piston running within the entirely airtight tube. The piston


**Figure 2:** The wagons of Thomas Mayall's elevated atmospheric system did not need any wheel.
was to be made of iron or steel, and tube of wood, terra cotta, glass or other nonmagnetic material. Inventors proposed two alternative designs. First, electromagnets could be located upon a car and powered from a stationary generator using rails as a circuit. In the second the electromagnets were placed inside a piston, with a circuit secured by two conducting rails running inside the tube.

**Systems with pneumatically operated mechanism mounted along the track**

This group comprises devices in which the propulsion is effected through the cooperation of the mechanism located along the track and a car-carried mechanism or car itself. It could be a series of mechanical devices powered by compressed air transmitted from stationary pump stations. Usually it was a number of arms or fixed rollers pushing a carriage along the track. According to the design of William Eccles the rollers were arranged every 90 cm along the whole length of a track and supported a car mounted on skids. When a skid pressed a lever the compressed air was delivered to the roller causing its spinning and thus the movement of the wagon.

The other manner was to place a flexible air hose along whole length of the route in combination with driving wheels attached to a wagon as in design of Ira Avery patented in 1847. When the air was forced into the pipe, it would impart to the wheel causing its rolling motion. Significantly it was the very first pneumatic railroad patent granted for an American in his country. The author however, a skillful patentee of several improvements in simple household machines, did not take any further steps to put that idea into practice. The next, who dealt with that system almost forty years later, was Milton Conger. His design was similar to that of Avery but, surprisingly, far less advanced.

**Vehicles powered by pneumatic engines**

Finally the compressed air could be used the same manner the steam was used for driving locomotives. Compressed air for pneumatic engine was to be either stored in a tank, or continual airflow from pump station should be secured. In the latter group
Figure 3: In the system of William Eccles the movement of the wagon was caused by successive action of fixed rollers. [source: Eccles William, Street-car Road, US Patent No. 377,930 dated February 14, 1888].

the most unusual way of accomplishing that was patented by Aylett Crihfield. A flexible hose being a half of the tracks’ length was to be placed inside a groove formed in the middle of the roadbed between the rails. In the middle of the route the hose was connected to a stationary engine. From the opposite end, the hose was joined with the revolving drum mounted upon a car. The drum was supposed to wind the flexible hose upon itself, as the train was running. A more feasible solution was proposed by George King of Washington. The tube, being laid along the whole length of the track, had a slot on its top covered by flexible sealing preventing the compressed air from escaping. A revolving air-conveyor with inlets on its edge was mounted on the bottom
Figure 4: Streetcars of Milton Conger were moving when the air where forced into the hose.  

Figure 5: Aylett Crihfield employed a revolving drum to wind propelling hose around it.  
of the car. While revolving, the subsequent inlets were entering the tube, thereby securing an interrupted airflow.

In most cases however the systems based on storing a quantity of the compressed air sufficient for propelling a train between charging station. In 1865 S.G. Randall patented a system in which the pipe conducting compressed air was provided with a number of outlets at suitable intervals along the track. Some inventors imagined refueling the reservoirs in any convenient point of the line. Others suggested charging automatically air-cylinders while train was in motion. Up to late 1890s numerous patents had been granted for the improvements in that system. Among them there were the designs of Whitcomb Judson, better remembered as inventor of a zipper. In spite of strong efforts of American engineers in that field, the tests that took place on the avenues of New York City were based on European devices. The Pneumatic 'Tramway Engine No. 1' was successfully tested on New York's elevated lines in 1881 and then in 1897. This was designed by a Scottish engineer Robert Hardie. Yet another, Louis Mekarski, a Polish born engineer of Paris had been experimenting with his pneumatic tramway in New York as well.

CONCLUSION

Although the idea of pneumatic railway is as old as the steam locomotion, it was mainly contemplated where steam traction could not be adopted. In 1840s the atmospheric railroads were suggested mainly on hilly sections, too sharp for contemporary locomotives. Later, in 1860s, it was proposed for underground city railway systems as it posed less ventilation problems than steam operated trains. In 1880s air powered tramways were operated in number of cities and tested in many others. They were cleaner than steam ones but not so convenient in operation as electric ones. Each time, when the advantages of pneumatic railroad systems were emphasized, they were compared to some disadvantages of steam locomotion. In Great Britain owning three of four atmospheric lines that were ever built, their share in the total length of railroads in this country had not exceeded 0.5 per cent. Meanwhile steam locomotives had their trials on thousands of miles worldwide thus, becoming more effective, faster, safer and powerful enough to climb step gradients. All advantages of pneumatic locomotion over steam traction, real or anticipated,
have just gone. Soon the pneumatically operated lines where closed and the failure of that means of communication had been announced. In fact it hardly ever had a chance to be fully developed. After closing atmospheric line connecting London with Croydon the editor of Scientific American wrote that ... this scheme had not we believe a fair trial. We should like every new scheme to get a fair trial before it is abandoned.31

Although the Americans dealt with pneumatic railway systems out of the main stream of interest in that scheme and their interest in that mode of communication dates back only to 1860s, the total number of patents granted by American Patent Office in entire 19th century exceeded seventy. That makes them the leaders on that field beside of English and French ones. In some cases they seemed to be not aware about disadvantages of proposed solutions that affected their European colleagues some forty years before. In nowadays paper works the achievements of American inventors are not presented except those of Alfred Beach who realized his dream in practical way and Rufus Gilbert, who is also remembered as that one who was so close to putting his system in operation. The others, sometimes very skilled inventors and manufacturers meritorious on other fields of technology, are almost completely forgotten as initiators of certain improvements

Figure 6: Number of patents related to air operated railways in USA in 1840–1899
in pneumatic systems. The system that was almost completely forgotten itself.

NOTES

1. Medhurst George, Calculations and remarks, tending to prove the practicability ... of a plan for the rapid conveyance of goods and passengers ... by the power and velocity of air, Londyn 1812


Pinkus got his first English patent in 1834, although he claimed to have been working on pneumatic propulsion since 1825. Presumably Henry Pinkus had never obtained a patent in the country of his origin, but it cannot be stated definitively. In fact, in 1826 he got an American patent for a Forest Railway, but since most of American patents issued before December 1836 were lost in the fire, it is difficult to recognize the substance of his invention.

3. Atmospheric Railways, The Congressional Globe 1833–1873, 10 February 1845, 123.


5. Beach Alfred, Improvement in Pneumatic Railways, US Patent No. 70,504 dated Nov 5, 1867


12. Reavis L.U., Saint Louis: the future great city of the world, 1871, 41


18. Mayall T.J., Prospectus of the Mayall Elevated Railway Companies: cable, electric, and pneumatic: three systems and seven modifications: three cable, one electric, and three pneumatic: adapted to all conditions of city streets, country highways, and land situations: capacity, speed, safety, and comfort: a marvelous combination: the systems of the future. Reading 1887

31. Atmospheric Railway in: Scientific American, June 22, 1847, 314