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The view from an expert

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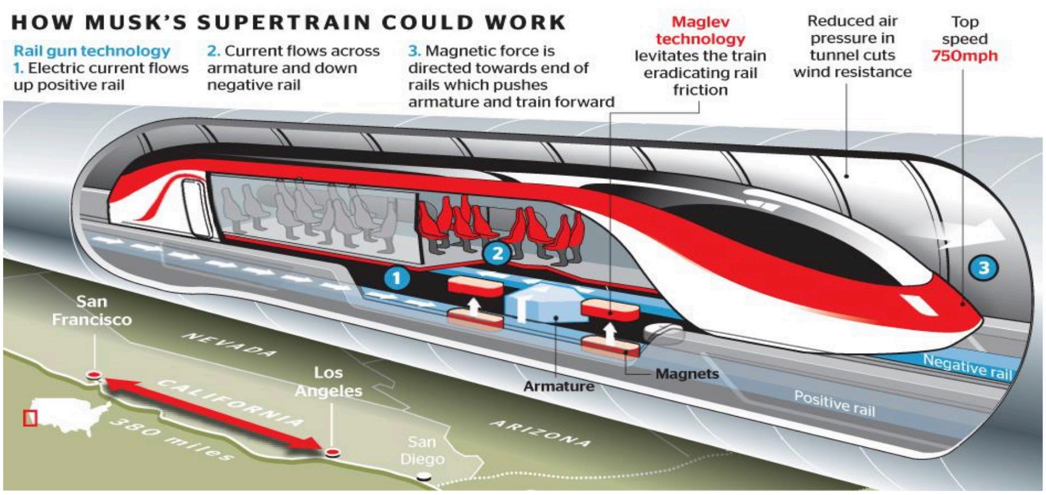
Hyperloop: a staggering intellectual and technical swindle

François Lacôte, French Civil Engineering Corps (1977), former CTO of Alstom Transport



Preamble: a postulate inaccurate from the start

Similarly to other guided terrestrial transportation projects reported as innovative (the French Aérotrain, German Transrapid, or the Japanese Maglev, all dating back to the seventies), the Hyperloop project is based on the stated principle that any wheel-rail system is subject to several limitations:
- a technical speed limit of about 125/150 mph: a false postulate since the speed record from April 3rd, 2017 was set at 357 mph during a test campaign over three winter months (from January to April 2007), during which 28 test rides were completed at speed above 310 mph with trains featuring near standard equipment, on plain tracks, without any additional maintenance operation of the train or the tracks other than simple inspection (that is without any reworking of any element of the train, of the track or the catenary), has showed that the current train system has a potential technical speed of at least 310 mph.
- an energy limit: while it is true that resistance to forward motion (hence the energy used for it) at air increases with speed, most of that resistance comes from aerodynamic resistance (increasing with the square of the speed), resistance due to the wheel-rail interface, already quite small, only accounts for a few percent of the total above 180 mph (an energy already small that the sustenance of other systems): therefore, all terrestrial transportation systems are subject to the same laws of aerodynamic resistance in air, where systems without wheel-rail contact do not gain any specific advantage; this context is of course different in the case of reduced pressure (planes at high elevation or terrestrial vehicle operating under vacuum.) For the rest, the energy cost is completely manageable: the fraction of energy in the exploitation cost of a French High Speed Train (TGV) operated at 180 mph is only about 5%, and it would remain small (14%) at 310 mph. Another depiction for this very small energy cost for TGV: during the record setting run on April 3rd, 2007, we travelled (from zero speed, therefore including the energy needed to bring the vehicle up to speed) 62 miles in 15 minutes, with 200 passengers on board.

The cost of electric energy (paid to the electricity provider) was only about $1.5 per passenger (in 2018 US dollars.)

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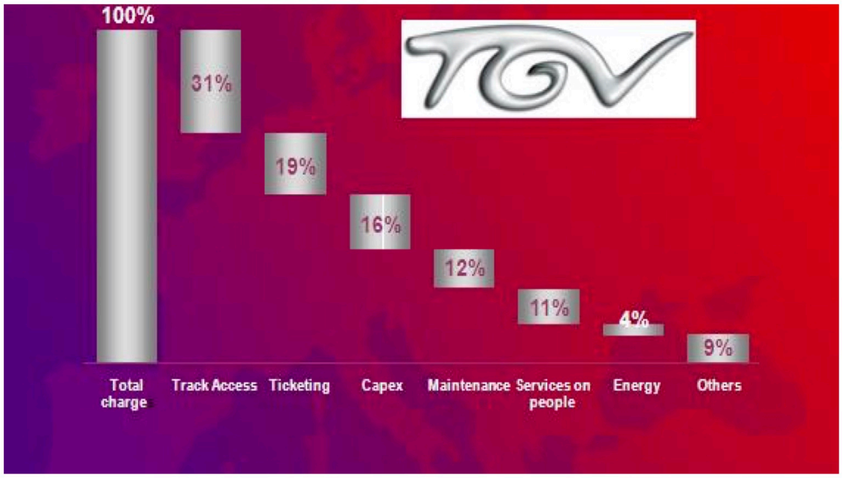


A breakdown of exploitation costs for French High Speed Train (TGV)

World speed record on rail: $1.5 per passenger for 60 miles travelled in under 15 minutes

- The infrastructure cost in only remotely related to rail transportation technology (few things are more affordable than rocks – ballast, and steel – the track), but it is mostly driven by the railway which has to become more and more straight as the cruise speed is increased, and therefore requires an increasing number of civil works of engineering (bridges and tunnels) in order to compensate for the natural variations of the elevation.

A little of history: nothing new!
Hyperloop is nothing but the rebranding of a very old project

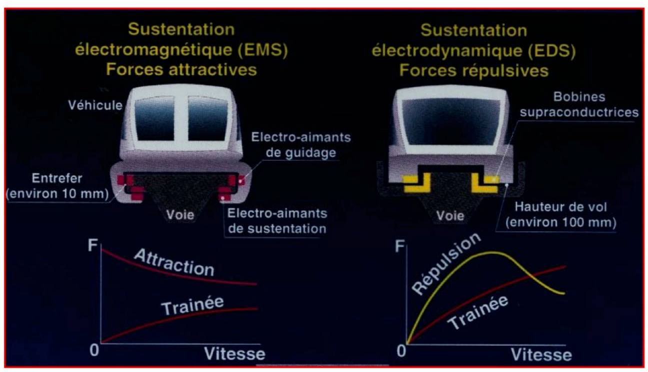
Let's recall that in the late sixties and early seventies, a lot of new terrestrial transportation systems were devised, and some developed at a high cost, rooted on the same idea that the train system was subject to limitations due to technical and economic constraints caused by the existence of a physical contact between the vessel and the infrastructure, the contact between the wheel and the rail.

Back then In France, the French engineer Jean Bertin invented, with the support of the government, the Aérotrain which was floating on air bearings and set in motion using propellers or jet engines.

In Germany, the companies Thyssen and Siemens, with additional support from the government, developed the Transrapid, a suspended train with magnetic guiding, and linear motor propulsion (using an elongated stator.)

The Aérotrain by French engineer Jean Bertin

In Japan, the Japan Rail company developed the Maglev, a train with magnetic suspension and guiding using repulsion, and propelled by a linear motor



Principle of operation for magnetic suspension
(left: the German design; right: the Japanese version)

The Transrapid and its track system

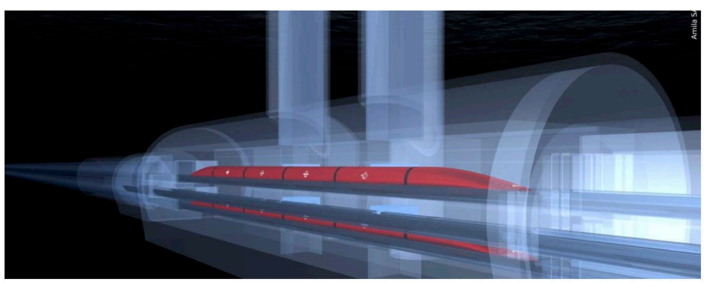
These three developments gave birth the the building of experimental railways: 12 miles in the Loiret (France, 1968), 25 miles in Emsland (Germany, 1984) for the Transrapid, and about 31 miles in the Yamanashi region (Japan, 1990), almost under Mt Fuji for the Maglev. Only the Yamanashi line is still in operation today, and there's only one in commercial exploitation: the Transrapid line connecting the Pudong Airport to Shanghai (22 miles); the other Transrapid projects initially envisioned, mostly in Germany, have all been abandoned.
Thus, 50 years after the first design studies of alternative terrestrial transportation designs, only one experimental line is in operational, and only one under commercial exploitation.

The Japanese Maglev on the Yamanashi experimental track

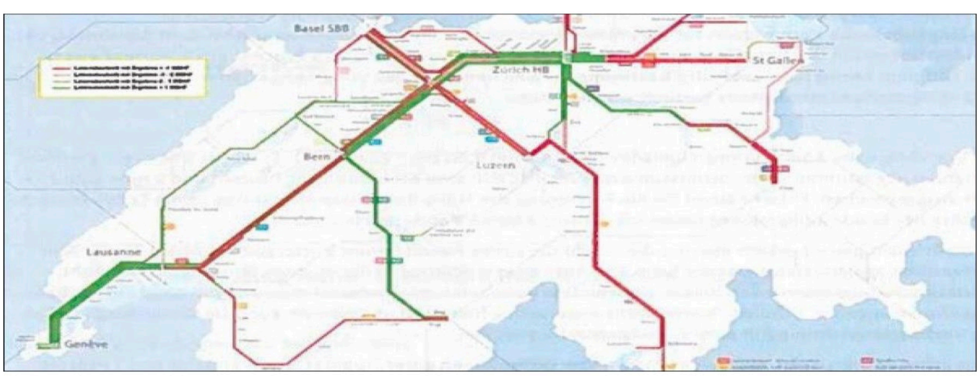
The reason for these failures are numerous, but there is no need here to list them all: it was only needed to remind the the Elon Musk concept for Hypeloop, with regard to the contactless operation between the track and the vessel, is 50 years old.

The "Swiss Metro" air vacuum tunnel

What about the idea of running a train under air vacuum, or rather under very low air pressure? This concept, based on the idea of a reduced resistance to motion, dates back from the seventies, and it was 26 years ago (January 1992) that the Swiss company Swissmetro was created to develop a project for a train with magnetic levitation circulating at very high speed (310 mph) in a tunnel with reduced air pressure (1/10 of atmospheric pressure.) This project brought very detailed studies, and funded in half by Switzerland, was abandoned about ten years ago, the company realizing, after the examination, that completion of this project would not be possible.



Swiss Metro in low air pressure tunnel



The (abandoned) Swiss Metro network

Therefore, the many elements that encompass the "Hyperloop" project can already be found in very long and very old projects, with many of them very advanced technically, and failed, for both economic and technical reasons.

Hyperloop: inconsistencies
Aerodynamic resistance: that's all you have to show for?

It seems that the concept for the Hyperloop system relies on one major goal: to reduce the resistance to motion, mostly for for aerodynamic reasons (but not only) at the envisioned cruise speed. We can already make two observations:

- at 200 mph cruise speed, the cost of energy in the exploitation cost is only 5%: it is therefore completely reasonable to consider increasing the cruise speed (say to 250 mph), leading to a 1.6x increase in energy cost (6.5% of the exploitation cost), without derailing the economic budget as far as energy is concerned.

- the improvement in transportation time decrease with speed (sad but true.) Thus, for a 360 miles journey, increasing the cruise speed by 60 mph shaves an hour (the trip takes only 2h) when changing from 120 mph to 180 mph, and an additional half hour when changing from 180 to 240 mph, but only 20 minutes when going from 250 to 300 mph, just over 10 minutes when going from 300 to 350 mph and so on… and only 6 minutes when going from 500 mph to 550 mph, the target cruise speed for Hyperloop, while other dimensioning parameters grow as the square, the cube or even more with increase in speed.

- the throughput of the Hyperloop line is disastrous: for a given deceleration (take for example emergency braking for TGV), the braking distance increases with the square of the speed. The safety distance between trains must obviously take into account this emergency braking distance: for a TGV running at 180 mph, 2 miles are required; with an identical deceleration (you don't want to picture yourself passengers nailed to their seat with security harness during the whole duration of the trip), this distance becomes 6.2 miles for a vessel running at 550 mph. You could consider (what has never been dared in rail transportation) to reduce this spacing by taking into account the speed of the preceding vehicle and its braking distance, but to a value of about 4 miles for self-evident safety reason. Whereas current High Speed Train systems allows for a 3 minute spacing between trains, or about 20 trains per hours, you wouldn't be able to do better than 6 minutes for Hyperloop (even using the "chaining" technique mentionned above), or a maximum theoretical throughput of 10 vessels an hour. Another aggravating consideration is that the unit capacity for the vessels is vastly different: a full TGV train with duplex configuration can convey 1000 passengers, while an Hyperloop vessel is limited to 100 passengers, or ten times less. Therefore, the theoretical throughput (1000 passengers per hour) is 20 times lower than that of TGV system (20,000 passengers per hour)! The resulting economic consequence is dire, even if the infrastructure cost were to be comparable – and it is actually much higher!

Hyperloop: technical dead-ends

System safety
- How do you deal with braking safety? Of course, main braking system is electromagnetic, but such a braking system is not deemed safe enough in any terrestrial transportation system (including rail transportation.) As a matter of fact, German and Japanese magnetic levitation systems do consider landing of the train on the track and rely on the friction between the vessel and the track for braking. What would be the solution for an Hyperloop vessel at 550 mph cruise speed?

- What kind of technical solution can be used for the rescue of passengers in a many hundred miles long tunnel under vacuum, in the event of an electricity shutdown, defective signaling, a faulty motor or any event resulting in prolonged vessel standby? Should you envision a network of compressed air with a multiplicity of gate valves all along the tunnel to allow for the supply in air of the complete section impacted by the vessel presence?

- More generally, whoever recalls the requirements of the Intergovernmental Security Commission related to the tunnel under the Channel (connecting France and Great Britain) can only blemish at the thought of what a public safety commission would require for the commercial exploitation with passengers.

Vessel/Station transition
- How would you transition from a vacuum environment to atmospheric pressure? It seems obvious that an airlock would be necessary, with moving doors blocking the tunnel to create a sealed volume that will progressively be filled with air to bring it up to atmospheric pressure. What technical solution can be used, and how much time will be lost in the process, keeping in mind that for example, in the previous calculation, going from 500 mph to 550 mph only saves you 6 minutes?

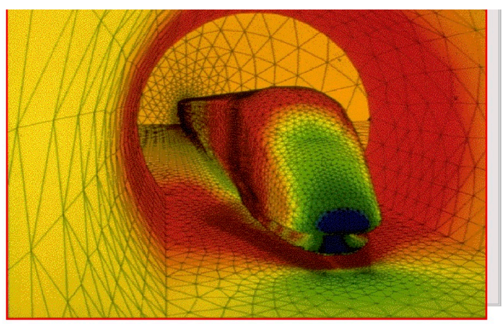
Geometry of the railway

The very high speed considered here (550 mph) implies that the track as to be as straight as possible, both in terms of lateral bends and elevation. Therefore, the argument that the ability of the vessel to climb steep slopes (what is true) would allow it to better match the elevation landscape is a complete imposture: effectively, in addition to the horizontal straightness (a bend radius of 30 miles to bring about the same level of comfort than TGV with 4 miles bend), it is necessary to point out the importance of the vertical radius of curvature (dips and bumps): from about 15 miles for a TGV running at 180 mph, they will have to be in the order of 125 miles at 550 mph! This shows that the track design will eventually lead to a succession of viaducts and tunnels, even for landscapes with the slightest of variations (i.e. anything other than the Great Salt Lake in the United States.) The ability to climb has not demonstrated advantages to show for.

Air pressure in the tunnel

The cooling of constitutive elements and resistance to motion, an impossible compromise! Independent of the otherwise overwhelming technical problems that comes with design of a continuous section of rarefied air over hundreds of miles, subject to thermal fluctuations and seismic constraints (at least for at aerial part of the tube), it is required to devise an impossible compromise between to contradictory goals:

- to reduce as much as possible the air pressure in the tunnel to reduce the aerodynamic resistance and the effect of pressure waves in the tunnel, in order to keep a reasonable diameter for the tunnel relative to the vessels,



Modeling pressure waves in a tunnel, to account for the effect of "pistonning"

- to keep at least some air pressure for the cooling of traction components, auxiliary energy, to allow for the renewal of the air for the HVAC system for passengers, and to keep within a reasonable range for the supply of air in the tunnel in case of an incident leading to the halting of the vessel.

During the design studies for the Swiss Metro Project, engineers from Ecole Polytechnique de Lausanne had suggested to keep an air pressure already quite low, in the order of a tenth of atmospheric pressure, what led to, considering a blocking ratio of 0.46 (ratio between the diameters of the vessel and the tunnel), to a resistance to forward motion comparable to that of atmospheric pressure in absence of a tunnel, and this for cruise speed of about 240 mph only.

Conclusion: why do something complicated when a simple solution is available?