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An overview of a hyperloop transport system for commercial applications

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Abstract

Hyperloop is proposed as a solution to the current limitation on ground transportation. Rolling and aerodynamic problems, that limit large speeds for traditional High-Speed Rail or maglev systems, are overcome using a hyperloop solution. This study shows that hyperloop systems can be optimum in terms of energy efficiency in medium-distance routes. Furthermore, it is stated that increasing the traction power on the vehicle and reducing it in the infrastructure greatly enhances scalability for long distances. Also, the use of aerospace pressure levels, instead of space ones, reduces infrastructure maintenance costs, weakens the requirements of the pumps, and increases safety. To determine the performance of hyperloop with respect to other means of transport, energy consumption, and travel time estimation are performed. This study leads to consider the proposed hyperloop concept as nearly as efficient as a train but with the operating times of a plane.

Keywords: hyperloop, evacuated-tube transport, maglev, ultra high-speed

1 Introduction

Hyperloop is getting more and more famous. It consists of the use of a ground-based transport system which has been covered with a tube. Thus, the atmosphere inside the tube can be controlled. If the air inside the tube is evacuated, a low-pressure environment is obtained and then, the aerodynamic resistance can be decreased, enabling higher speeds with the same energy consumption. If levitation is added to the system, no resistance with the ground exists and one of the major limitations of the traditional trains, the rolling, is overcome. Also, expensive rail maintenance is overcome.

The history of this concept begins over 200 years ago when in 1799 the English inventor George Medhurst [1] first proposed moving passenger carriages through a tunnel using variations in pressure levels. Some systems were implemented in France [2,3], England [4], and Ireland [5] during the 19th century. The system was called "Atmospheric Railway".

A century later, in 1904 Robert Goddard at Worcester Polytechnic Institute (USA) combines the concept of airless tunnels to reduce air friction with the concept of magnetic levitation ("maglev") [6] systems to reduce the ground friction losses. This concept could enable very high speeds. Russian inventor Boris Weinberg built his first model in 1909 at Tomsk University [7]. During the following years, the evolution of both technologies (low-pressure tubes and magnetic levitation systems) advanced in parallel. The development of the first superconducting (SC) levitation technologies [8] and linear motors [9] led to the creation of maglev trains. Concurrently, advances in space led to the development of high-volume vacuum systems, like the Large Hadron Collider, with a total of 104 kilometers of piping under vacuum [10]. In the late 1970s, Professor Marcel Jufer from Switzerland combined again both ideas of low pressure and magnetism proposing Swissmetro [11]. In August 2013, American businessman Elon Musk publishes online an open whitepaper called "Hyperloop Alpha" [12], with a concept of air-bearings for levitation and linear motors at each station for propulsion.

From this date, hyperloop companies arose globally in order to develop such a system, and cooperation agreements have been announced to enable international standardization ensuring interoperability [13].

Apart from the technology, the necessity of a new means of transport is becoming more and more evident [14]. The trends show an ever-increasing increment for all distances, particularly relevant to the segment where high-speed trains and planes share or overlap their market borders.

2 Methods

The combination of low pressure and levitation reduces the main drag on a train. Thus, low energy consumption is required on the proposed system, leading it to be as fast as the plane, with the sound barrier as the theoretical main limit (around 1250 km/h). This speed is twice the largest speed ever obtained by a High-Speed Rail [15] and Maglevs.

However, as hyperloop is a new concept, several approaches have been taken when it comes to its actual development. Zeleros concept (see Figure 1) can be mainly divided into two different systems.

Figure 1: Overview of Zeleros' hyperloop concept.

On the one hand, levitation is based on Hybrid Electromagnetic Suspension (HEMS). Permanent magnets surrounded by electromagnets are placed on the vehicle. The permanent magnets account for lifting the weight of the vehicle, while the electromagnet is responsible for controlling the gap with the tube. This way, low power is required to energize the coils, as most of the effort corresponds to the permanent magnets.

On another hand, propulsion is based on a simplified aeronautical engine, in which the combustion chamber has been removed. A compressor driven by an electric motor captures the air in front of the pod, compresses it, and exhausts it through a nozzle to generate thrust and overcome the drag. This overcomes the problem of traveling inside a tube, where, even at low pressure, air ends up being blocked in front of the vehicle as it happens with trains inside tunnels.

One of the main advantages of this proposal is that, as all the technology is integrated into the vehicle, the track complexity is significantly reduced compared to other approaches that based their propulsion on linear motors. As no coils or permanent magnets are required on the track, the infrastructure cost is considerably reduced.

From the safety and reliability point of view, higher pressures allow the use of these systems with confidence at 10 kPa. The Concorde proved successfully that pressurized cabins and turbofans engines could operate successfully at pressures lower than 7 kPa.

A lower limit could be established at the Armstrong limit of 6.26 kPa [16]. Operating pressures lower than the Armstrong limit not only could decrease the efficiency of the turbomachinery but also make it unfeasible for massive passenger transportation systems due to the survivability in case of depressurization (see Figure 2).

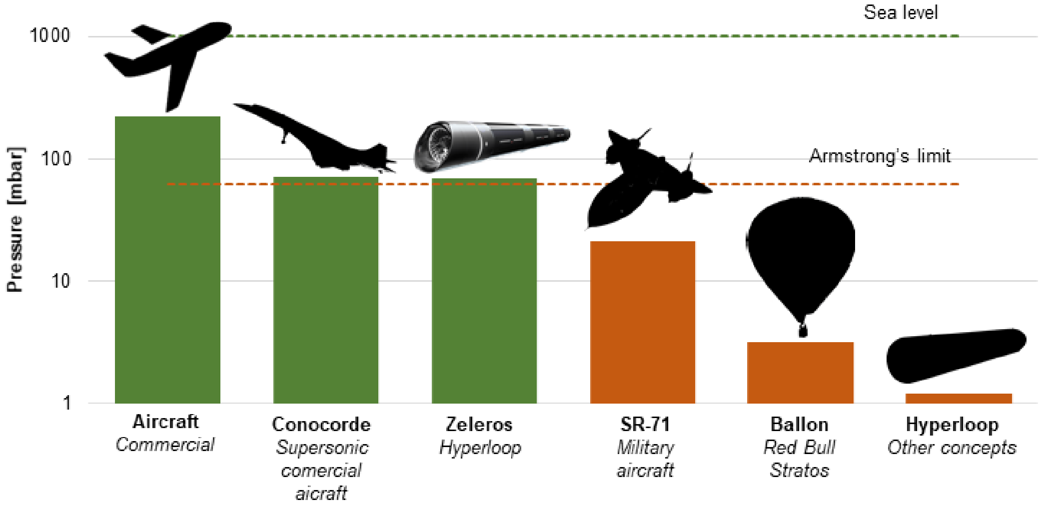

Figure 2: Operating pressures for different vehicles. Reference SR-71 [17], reference balloon [18].

3 Results

For the present paper, a dynamic simulator was developed to estimate the cost in time and energy that our concept requires and the capacity of the system.

With that in mind, it has been proven that vehicles can be built to accommodate up to 200 passengers. As the most widespread narrowbody aircraft, A320, and B737, can carry up to 185 passengers, the presented system matches the true market needs. In those conditions, the minimum headway at cruise speed is around 2.5 minutes, which means, considering 16 hours of daily operation, 76,800 passengers per day per direction.

In Figure 4 (right) the energy consumption for the developed simulator is compared with plane and train alternatives, for a 1,000 km route.

As it can be seen, the train is the most energy-efficient one. However, its competitiveness in distances higher than 1,000 km is limited due to its resulting average speed. When hyperloop is compared with air services, improvements of 58% are depicted. The main reason being the cruise (the most energy-efficient flight phase) represents a low share of the total flight time (as seen in Figure 3).

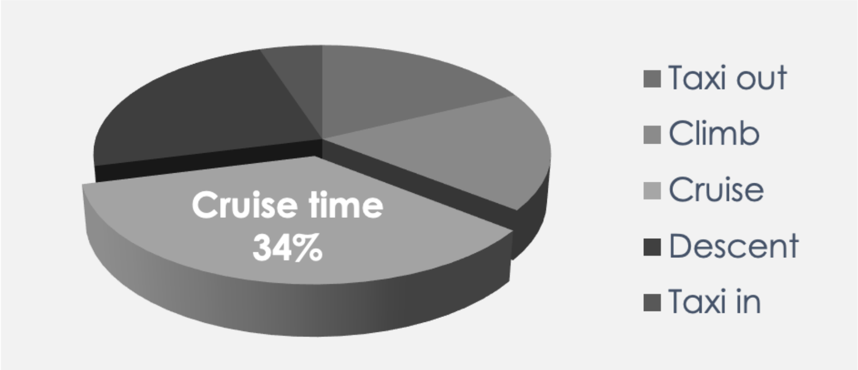

Figure 3. Time of flight-phase for a 1,000 km route. Reference: flightaware.com

In addition, a compounded indicator aggregating journey time and energy consumption, shown in Figure 4 (left), depicts aircraft as the lowest performer, while train, and especially European High-Speed Rail (HSR), outperforms the other solutions. High-speed rail routes spanning more than 1,000 kilometres are uncommon. Furthermore, the intermediate stops lower the average speed and further decrease HSR's competitiveness. The combination of these factors turn hyperloop into the most competitive form of transport for medium-range routes.

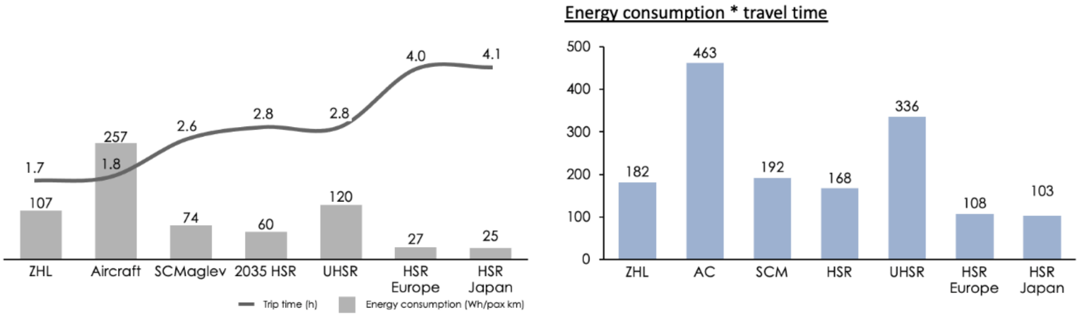

Figure 4: Right: Travel time from the developed simulator compared with plane and train. Left: Aggregated indicator, energy consumption * travel time

4 Conclusions and Contributions

- Hyperloop could result in an optimal transport solution, combining the low aerodynamic due to the low-pressure environment inside the tube and the absence of rolling friction.
- The closed environment, which shields the system from external weather, makes it more robust than traditional means of transport regarding adverse weather conditions such as heavy rain, strong crosswinds, blizzards, etc.
- The proposed system is optimal for hubs between 500 km and 1500 km, on the border between ground and air transportation.
- The system for medium distances could be even 4 times more energy-efficient than an aircraft with 0 direct emissions and similar travel time. Compared to

the High-Speed Rail, Zeleros' hyperloop can be as efficient as that system, being considerably faster.

- Saturation of airways is already a reality in some corridors. Hyperloop can complement the current air and/or rail corridors with another transportation layer, up to 76,800 passengers per day (one way).

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