Knowledge Consortium of Gujarat
Department of Higher Education - Government of Gujarat
Journal of Multi-Disciplinary - ISSN : 2279-0268

Continuous Issue -33| December– January 2020

HYPERLOOP: THE FIFTH MODE OF TRANSPORTATION

Abstract

Existing conventional modes of transportation consists of four unique types: rail, road, water, and air. These modes of transport tend to be either relatively slow (i.e., road and water), expensive (i.e. air) or a combination of relatively slow and expensive (i.e. rail). Hyperloop is innovative mode of transport that seeks to change this paradigm by being both fast and inexpensive for transportation. This new approach uses both permanent magnets and electromagnets to levitate, propel, and control a pod. The electro dynamic suspension system is emulated as a small pod attached with permanent magnets from the bottom, which resembles a short-rotor linear synchronous motor.

Passengers may enter and exit Hyperloop at stations located either at the ends of the tube, or branches along the tube length. In this study, the initial route, preliminary design, and logistics of the Hyperloop transportation system have been derived. Recently Virgin Hyperloop group plans to inaugurate a hyperloop linking the two INDIAN cities (Mumbai-Pune) that will cut down travel time to 13 minutes, or less instead of 2 hr. with conventional mode.

It quickly becomes apparent just how dramatically the Hyperloop could change transportation, road congestion and minimize the carbon footprint globally. With the Hyperloop, extremely fast, inexpensive intercity travel would be widely accessible. If both people and goods can move more quickly and comparatively cheaply, rapid growth is a logical outcome.

1. Introduction

A Hyperloop is a proposed mode of passenger and/or freight transportation, first used to describe an open-source vactrain design released by a joint team from Tesla and Space X. A hyperloop is a sealed tube or system of tubes through which a pod may travel free of air resistance or friction conveying people or objects at high speed while being very efficient.

The Hyperloop Alpha concept was first published in August 2013, proposing and examining a route running from the Los Angeles region to the Francisco Bay Area, roughly following the Interstate 5 corridor. The Hyperloop Genesis paper conceived of a hyperloop system that would propel passengers along the 560 km route at a speed of 1,200 km/h allowing for a travel time of 35 minutes, which is considerably faster than current rail or air travel times.

If we are to make a massive investment in a new transportation system, then the return should by rights be equally massive. Compared to the alternatives, it should ideally be:

- Safer
- Faster
- Lower cost
- More convenient
- Immune to weather
- Sustainably self-powering
- Resistant to Earthquakes
- Not disruptive to those along the route

2. Background of the Invention

The corridor between San Francisco, California and Los Angeles, California is one of the most often travelled corridors in the American West. The current practical modes of transport for passengers between these two major population centres include:

1. Road (inexpensive, slow, usually not environmentally sound)
2. Air (expensive, fast, not environmentally sound)
3. Rail (expensive, slow, often environmentally sound)

A new mode of transport is needed that has benefits of the current modes without the negative aspects of each. This new high-speed transportation system has the following requirements:

1. Ready when the passenger is ready to travel (road)
2. Inexpensive (road)
3. Fast (air)
4. Environmentally friendly (rail/road via electric cars)

The onboard compressor is also used to improve the efficiency of the pod at higher speeds. Once the pod reaches transonic speeds, the flow around the pod will start to choke, i.e. the flow around the pod will become sonic. At this sonic condition the so-called Kantrowitz limit. The mass flow around the pod is at its maximum. Therefore, when the speed is further increased, not all flow can travel around the pod and is therefore collected in front of the pod. The result is a column of air being pushed by the pod throughout its run. That pressure build-up results in significant additional drag. The Hyperloop Alpha concept therefore introduces the on-board compressor to compress the additional flow and suck it through the pod, while at the same time supplying compressed air to the air bearings.

A new high-speed mode of transport is desired between Los Angeles and San Francisco; however, the proposed California High Speed Rail does not reduce current trip times or reduce costs relative to existing modes of transport. This preliminary design study proposes a new mode of high-speed transport that reduces both the travel time and travel cost between Los Angeles and San Francisco. Options are also included to increase the transportation system to other major population centres across California. It is also worth noting the energy cost of this system is less than any currently existing mode of transport the only system that comes close to matching the low energy requirements of Hyperloop is the fully electric Tesla Model S.

3. Design Description

Hyperloop is a proposed transportation system for travelling between Los Angeles, California, and San Francisco, California in 35 minutes. The Hyperloop consists of several distinct components including:

1. Capsule:

a. Sealed capsules carrying 28 passengers each that travel along the interior of the tube depart on average every 2 minutes from Los Angeles or San Francisco (up to every 30 seconds during peak usage hours).

b. A larger system has also been sized that allows transport of 3 full size automobiles with passengers to travel in the capsule.

c. The capsules are separated within the tube by approximately 23 miles (37 km) on average during operation.

d. The capsules are supported via air bearings that operate using a compressed air reservoir and aerodynamic lift.

2. Tube:

a. The tube is made of steel. Two tubes will be welded together in a side by side configuration to allow the capsules to travel both directions.

b. Pylons are placed every 100 ft (30 m) to support the tube.

c. Solar arrays will cover the top of the tubes in order to provide power to the system.

3. Propulsion:

a. Linear accelerators are constructed along the length of the tube at various locations to accelerate the capsules

b. Stators are located on the capsules to transfer momentum to the capsules via the linear accelerators.

4. Route:

a. There will be a station at Los Angeles and San Francisco. Several stations along the way will be possible with splits in the tube. b. The majority of the route will follow I-5 and the tube will be constructed in the median.

CAPSULE

Two versions of the Hyperloop capsules are being considered: a passenger only version and a passenger plus vehicle version.

Hyperloop Passenger Capsule

Assuming an average departure time of 2 minutes between capsules, a minimum of 28 passengers per capsule are required to meet 840 passengers per hour. It is possible to further increase the Hyperloop capacity by reducing the time between departures. The current baseline requires up to 40 capsules in activity during rush hour, 6 of which are at the terminals for loading and unloading of the passengers in approximately 5 minutes.

Hyperloop Passenger Plus Vehicle Capsule

The passenger plus vehicle version of the Hyperloop will depart as often as the passenger only version, but will

Accommodate 3 vehicles in addition to the passengers. All subsystems discussed in the following sections are featured on both capsules.

For travel at high speeds, the greatest power requirement is normally to overcome air resistance. Aerodynamic drag increases with the square of speed, and thus the power requirement increases with the cube of speed. For example, to travel twice as fast a vehicle must overcome four times the aerodynamic resistance, and input eight times the power.

Hyperloop Passenger Capsule

The maximum width is 4.43 ft (1.35 m) and maximum height is 6.11 ft (1.10 m). With rounded corners, this is equivalent to a 15 ft2 (1.4 m2) frontal area, not including any propulsion or suspension components.

The aerodynamic power requirements at 800-900 kph is around only 100 kW with a drag force of only 320 N, or about the same force as the weight of one oversized checked bag at the airport. The doors on each side will open in a gullwing (or possibly sliding) manner to allow easy access during loading and unloading. The luggage compartment will be at the front or rear of the capsule.

The overall structure weight is expected to be near 3,100 kg including the luggage compartments and door mechanism.

TUBE

The main Hyperloop route consists of a partially evacuated cylindrical tube that connects the Los Angeles and San Francisco stations in a closed loop system. The tube is specifically sized for optimal air flow around the capsule improving performance and energy consumption at the expected travel speed. The expected pressure inside the tube will be maintained around 0.015 psi (100 Pa, 0.75 torr), which is about 1/6 the pressure on Mars. This low pressure minimizes the drag force on the capsule while maintaining the relative ease of pumping out the air from the tube. The efficiency of industrial vacuum pumps decreases exponentially as the pressure is reduced, so further benefits from reducing tube pressure would be offset by increased pumping complexity.

PASASENGER HYPERLOOP TUBE

The inner diameter of the tube is optimized to be 7 ft 4 in. (2.23 m) which is small enough to keep material cost low while large enough to provide some alleviation of choked air flow around the capsule. The tube cross-sectional area is 42.2 ft^2 (3.91 m2) giving a capsule/tube area ratio of 36% or a diameter ratio of 60%. It is critical to the aerodynamics of the capsule to keep this ratio as large as possible, even though the pressure in the tube is extremely low. As the capsule moves through the tube, it must displace its own volume of air, in a loosely similar way to a boat in water. The displacement of the air is constricted by the walls of the tube, which makes it accelerate to squeeze through the gaps. Any flow not displaced must be ingested by the onboard compressor of each capsule, which increases power requirements.

The closed loop tube will be mounted side by side on elevated pillars as seen in Figure 5. The surface above the tubes will be lined with solar panels to provide the required system energy. This represents a possible area of 14 ft (4.25 m) wide for more than 350 miles (563 km) of tube length. With an expected solar panel energy production of 0.015 hp/ft^2 (120 W/m^2), we can expect the system to produce a maximum of 382,000 hp (285 MW) at peak solar activity. This would actually be more energy than needed for the Hyperloop system.

Tube Construction

In order to keep cost to a minimum, a uniform thickness steel tube reinforced with stringers was selected as the material of choice for the inner diameter tube Tube sections would be pre-fabricated and installed between pillar supports spaced 100 ft (30 m) on average, varying slightly depending on Location.

This relatively short span allows keeping tube material cost and deflection to a minimum.

The steel construction allows simple welding processes to join different tube sections together. A specifically designed cleaning and boring machine will make it possible to surface finish the inside of the tube and welded joints for a better gliding surface. In addition, safety emergency exits and pressurization ports will be added in key locations along the length of the tube.

Pylons and Tunnels

The tube will be supported by pillars which constrain the tube in the vertical direction but allow longitudinal slip for thermal expansion as well as dampened lateral slip to reduce the risk posed by earthquakes. In addition, the pillar to tube connection nominal position will be adjustable vertically and laterally to ensure proper alignment despite possible ground settling. These minimally constrained pillars to tube joints will also allow a smoother ride. Specially designed slip joints at each station will be able take any tube length variance due to thermal expansion. This is an ideal location for the thermal expansion joints as the speed is much lower nearby the stations. It thus allows the tube to be smooth and welded along the high-speed gliding middle section.

The spacing of the Hyperloop pillars retaining the tube is critical to achieve the design objective of the tube structure. The average spacing is 100 ft (30 m), which means there will be near 25,000 pillars supporting both tubes and solar panels. The pillars will be 20 ft (6 m) tall whenever possible but may vary in height in hilly areas or where obstacles are in the way. Also, in some key areas, the spacing will have to vary in order to pass over roads or other obstacles. Small spacing between each support reduces the deflection of the tube keeping the capsule steadier and the journey more enjoyable. In addition, reduced spacing has increased resistance to seismic loading as well as the lateral acceleration of the capsule.

ROUTE

The Hyperloop will be capable of travelling between Los Angeles and San Francisco in approximately 35 minutes. This requirement tends to size other portions of the system. Given the performance specification of the Hyperloop, a route has been devised to satisfy this design requirement.

The Hyperloop route should be based on several considerations, including:

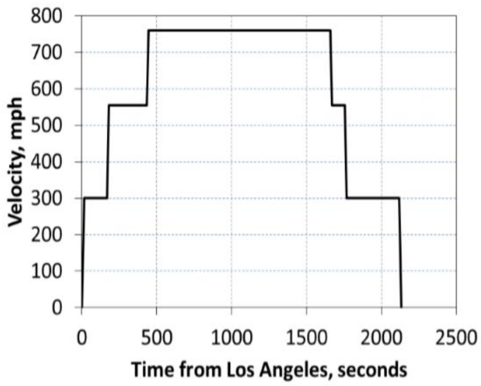
1. Maintaining the tube as closely as possible to existing rights of way (e.g., following the I-5).

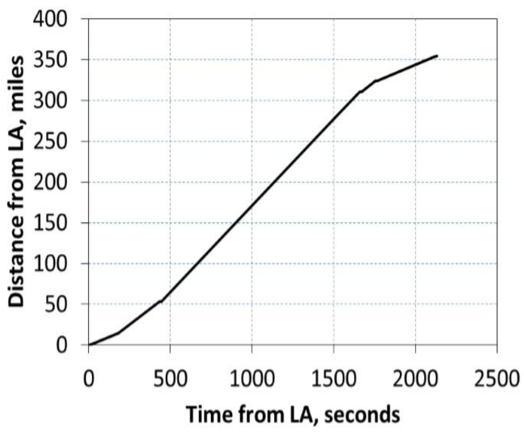
2. Limiting the maximum capsule speed to 760 mph (1,220 kph) for aerodynamic considerations.

3. Limiting accelerations on the passengers to 0.5g.

4. Optimizing locations of the linear motor tube sections driving the capsules.

5. Local geographical constraints, including location of urban areas, mountain ranges, reservoirs, national parks, roads, railroads, airports, etc. The route must respect existing structures.





4. Conclusion

The aerodynamic design strategy was two-fold. First, geometry sweeps were performed using a fast ax- symmetric viscous/in viscid analysis tool, while accounting for different flow rates between the ax symmetric and 3D shape. In the aerodynamic design it was crucial to transition the boundary layer to turbulent close to the front of the pod such that higher adverse pressure gradients are tolerated before separation. Such a design strategy increases friction drag but dramatically reduces pressure drag. Once the ax symmetric shape was decided upon, the final three-dimensional geometry was analyzed using a three-dimensional Naiver-Stokes solver to characterize its final performance at design speed.

Concluding, for the aerodynamic flow regime for this SpaceX Hyperloop Pod Competition, a droplet shaped aerodynamic shell is most elective at delaying flow separation, lowering the drag substantially. By investigating the performance of the design at transonic speed, it was also found that violating the Kantrowitz limit could lead to three-fold increase in drag coefficient for an increase in Mach number from 0.65 to 0.80.

References

I. A NEW FUTURE FOR HYPERLOOP TECHNOLOGY, International Journal of Innovative Research in Technology (www.ijirt.org) ,ISSN: 2349-6002 ,Volume 4 ,Issue 11 ,Page(s):962-967 ,April 2018.

II. Hyperloop Transportation System, by Cikitusi Journal for Multidisciplinary Research, Volume 6, Issue 4, April 2019.

III. The Deal With the Hyperloop, June 15, 2015 By Tim Urban.

IV. Review of Hyperloop : The Fifth Mode of Transport by Rohan Jacob, Rachel Phillip, Sonu Sunny, Joso George in International Journal of New Technology and Research (IJNTR) ISSN:2454-4116, Volume-3, Issue-3, March 2017.

V. Aerodynamic Design of the Hyperloop Concept by Max M. J. Opgenoord∗ and Philip C. Caplan.

VI. https://en.wikipedia.org/wiki/Hyperloop

VII. https://www.investopedia.com/articles/investing/050815/elon-musks-hyperloop-economically-feasible.asp

VIII. https://www.spacex.com/sites/spacex/files/hyperloop_alpha.pdf

IX. https://leancrew.com/all-this/2013/08/hyperloop/

X. https://www.zdnet.com/article/what-is-hyperloop-everything-you-need-to-know-about-the-future-of-transport/

****

Prof. Kartik Zala
Department of Civil Engineering,
Swarrnim Startup & Innovation University
Gandhinagar

Prof. Mansi Prajapati
Department of Civil Engineering,
Swarrnim Startup & Innovation University
Gandhinagar