



# A Look Inside a New Mode

## *Virgin Hyperloop One*

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Irfan Usman, Virgin Hyperloop One Senior Levitation Design Engineer, bent over the test rig, adjusting the cables and checking the sensors before turning on the system. A giant machine whirred to life, lifting a heavy piece of metal up to its counterpart component under the force of an unseen power. The piece of metal slid back down again gently and a room full of engineers cheered—it was the birth of the highest-performance transportation magnetic levitation system in history. It did not happen in a well-funded national research lab or in the research department of a major Fortune 500 company, but in an old industrial ice factory repurposed into the offices of a start-up in the Arts District of Los Angeles.

In 2014, the hyperloop was an idea, a series of obscure equations sketched on a whiteboard in a garage, unintelligible to all except for rocket scientists. Elon Musk had recently published “Hyperloop Alpha,” a white paper in which he outlined the technical components of a new mode of transportation that was faster, greener, and more energy-efficient than any existing mode—the hyperloop.<sup>1</sup> This idea captured the imagination of many futurists, technologists, and transport officials; shortly after Musk published his paper, Virgin Hyperloop One—then called Hyperloop Technologies—was founded. Three years later, Virgin

<sup>1</sup> [www.spacex.com/sites/spacex/files/hyperloop\\_alpha-20130812.pdf](http://www.spacex.com/sites/spacex/files/hyperloop_alpha-20130812.pdf).

DevLoop site in Nevada, a 500-m complete system test track.



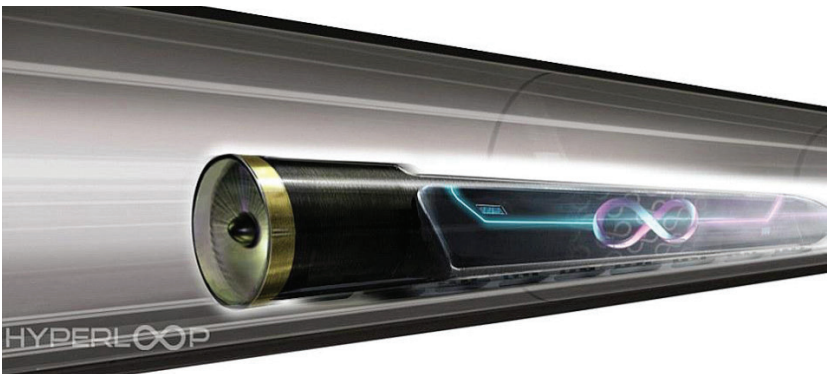
Design engineers at Virgin Hyperloop One's headquarters.

Hyperloop One built the world's first full-scale, full-system hyperloop test track.

How did it happen in such a short time? Rapid prototyping—the development and testing of components early in the design process to understand how materials work in practice—is a key design principle at the company, ingrained in each engineer when they join and emphasized in the spatial layout of the office. The Test and Development Center is located next to the offices of the company's design engineers, separated only by a coffee bar.

Once the design engineers designed the components and confirmed that they worked in theory, experienced welders and technicians built to the design specifications, making sure that the components worked as the math had predicted. This joint effort is driven by the recognition that builders and tradespeople are just as important as the designers. The principle of rapid designing, building, testing, and redesign was key to the ability to develop parts rapidly and to learn from early mistakes.

Early rendering of the hyperloop pod, with the air bearings and compressor in front.



One critical component of the technology proposed in the “Hyperloop Alpha” white paper was the usage of air bearings to levitate the pod. According to Musk, “air bearings, which use the same basic principle as an air hockey table, have been demonstrated to work at speeds of Mach 1.1 with very low friction.” Air bearings are known to be energy efficient and to have high performance.

## Testing in a Vacuum

In June 2015, Hyperloop Technologies ordered an autoclave, a piece of equipment similar to a giant pressure cooker. Autoclaves commonly are used for a multitude of industrial purposes, including curing aerospace parts and other types of composites. In this case, however, the purpose of the autoclave was to create a near-vacuum environment to test levitation. A small team of engineers carefully built and installed a levitation rig—a device used to simulate levitation in a vacuum—within the autoclave. The specifications outlined in Musk's white paper were carefully measured out, built, and tested.

The results were depressing. It quickly became apparent that an enormous amount of power was needed to compress air in a partial vacuum to fuel the air bearings. Contrary to what was proposed in the white paper, this design was neither energy-efficient nor cost-effective. The air gap between the tube-shaped track structure and the bottom of the pod was extremely small; therefore, the dimensional tolerances required of the entire system were extremely high. This meant that the track needed to be nearly perfectly aligned, making it difficult to account for expansions or contractions due to temperature or other factors. For example, a hot day might cause the track to fall out of alignment. Heavy maintenance would be required, and the costs of installing and maintaining a track with such high-tolerance requirements would be massive.

## Switching Tracks

The vacuum test quickly led to the decision to move from air bearings to magnetic levitation. This was a fundamental shift in the design of the modern Virgin Hyperloop One system. The air compressor—the fan seen at the front of the pod in many early renderings of the hyperloop system—also was discarded. Without air bearings, the need to reduce the air at the front of the pod and improve aerodynamic drag in a near-vacuum environment was minimal.

Magnetic levitation is a well-known and tested technology that has been on the market for more than 30 years. The Levitation, Power Electronics, and Test and Development teams at Virgin Hyperloop One spent months designing the ultimate mag-



netic levitation system. The team experimented with different types of track, composed of materials ranging from the commonplace—steel and aluminum—to the sophisticated, such as superconductors.

Researchers experimented with different electrical currents and various rig configurations. The specifications were clear: the system needed to have similar levitation properties as air bearings, but with a higher ride height and a design to tolerate larger variances in gap. The team at Virgin Hyperloop One understood how the technology worked, but needed to make it better—that is, cheaper and easier to implement.

Rapid prototyping allowed the team to pivot quickly from a theoretically correct but impractical design for a key component of the system to one that performed better in practice. For a new start-up with vast ambitions, it was important to focus the design process. The more focused the process was, the less money was wasted and the less time was spent on designs that ultimately would be scrapped.

## Full-Scale Testing

In May 2017, Hyperloop One ran its first full-system test on its DevLoop system, a 500-m test track in the Nevada desert approximately 40 mi outside of Las Vegas. DevLoop is short for “Development Loop,” the first functioning hyperloop system in the world, complete with power electronics, an autonomous pod, motor control and braking systems, levitation track, guidance systems, and more than 1,100 tons of steel and concrete. The vacuum pumps reduced the air in the tube to 100 pascals, or approximately 1/1,000 standard atmospheric pressure.

On July 29, 2017, Phase 2 testing was complete. XP-1, the only vehicle in the world that can achieve autonomous high-speed propulsion and levitation in a vacuum environment, accelerated from zero to 192 mph and back to zero mph again over a distance of less than 500 m. Acceleration g-forces hit nearly 1.48—the equivalent of going from zero to 60 mph in 1.85 s. This marked a momentous occasion in the company’s history and was a testament to the team that put it all together in just three years.

Less than five months later, XP-1 achieved even faster speeds. The company also tested a new airlock system to transition test pods between atmospheric and vacuum conditions. On December 15, 2017, Virgin Hyperloop One set a test-speed record during its Phase 3 testing at DevLoop: nearly 240 mph.

Yet despite its achievements, critiques of DevLoop included the following: “It doesn’t go as fast as they said it would,” “it’s not as big as they said it would be,” and “it can’t carry passengers.” DevLoop was never meant to carry passengers or test pods at 700 mph, the hyperloop design speed, however. The



PHOTO: VIRGIN HYPERLOOP ONE

DevLoop design was purposeful and meaningful: to test as much as it could as cheaply and as quickly as possible, and to stress test the integration of the system without overengineering the entire system.

For example, the tube track was built smaller than the size required for production—3.3 m rather than 4–5 m—but the smaller size meant that the tube was big enough to stress-test the welds between tube segments and the system’s structural stability without spending more than necessary on steel or supporting columns. Although the tube was not long enough to allow the pod to reach its full speed of 700 mph, DevLoop ensured that all the components functioned together as theoretically designed—and that ultimately achieving 700-mph speeds would be only a matter of distance.

As these technology milestones were reached,

Test and development area at the Virgin Hyperloop One headquarters.

The XP-1 pod at the Nevada site.



PHOTO: VIRGIN HYPERLOOP ONE



PHOTO: THOMAS HAWK, FLICKR

Elon Musk has open-sourced his hyperloop concept for others to design and develop.

Virgin Hyperloop One moved toward commercialization, focusing on developing markets.

## Global Challenge

During the unveiling of the hyperloop's propulsion system in May 2016, Virgin Hyperloop One launched the Hyperloop One Global Challenge to gather feedback from customers and stakeholders as to where the first routes should be built.

The results of the Global Challenge far exceeded expectations. Proposals were received from 25 countries. Of these, the company selected 35 semifinalists—including 20 that had strong governmental support—and announced the ten winning routes in September 2017. The company also launched global events in Delhi, India; Amsterdam, Netherlands; and Washington, D.C., bringing together major government stakeholders and private-sector representatives to discuss the future of transportation. The Global Challenge results demonstrated how quickly public and private sectors could come together to make hyperloop systems a reality around the world.

The ten winning routes were judged based on a few factors: ease of construction, a compelling business case, a favorable regulatory environment, and strong political support. Considered were the following questions:

- ◆ Would there be any technically challenging hurdles in the construction of a hyperloop along this corridor?

- ◆ Is there sufficient ridership and demand to justify the construction and operations of a new transportation corridor?

- ◆ Is there strong and sufficient political support?
- ◆ Is this an organization that can move quickly in bringing both private and public stakeholders together?

## RoadX in Colorado

One of the most impressive applications, spearheaded by then-Executive Director Shailen Bhatt, was submitted by the Colorado Department of Transportation (DOT). In April, Bhatt and his team traveled to Washington, D.C., for the Hyperloop One Vision for America event. The Rocky Mountain Hyperloop team included a diverse group of stakeholders in addition to Colorado DOT: RoadX, a relatively new agency within the DOT that evaluates and implements such new technologies as autonomous cars and truck platooning; the High-Performance Transportation Enterprise, which develops innovative means to finance new technologies; Denver International Airport, which saw in the hyperloop project the potential for development of an aerotropolis; and the global engineering firm AECOM. The team saw a clear vision in what hyperloop could bring to the state of Colorado: a remedy to congestion stemming from a system built nearly 70 years ago.

“Colorado’s transportation network was planned in the 1950s and built in the 1960s for the population of the 1980s,” Bhatt observes.



PHOTO: HOBBIE CADWELL, FLICKR

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Colorado Department of Transportation’s (DOT’s) RoadX, an agency focused on new technologies, submitted a hyperloop proposal to the Hyperloop One Global Challenge. Among the goals of a hyperloop system in Colorado would be to decrease rural highway fatalities.



By 1990, Colorado's population had reached 3 million; today, the state's population is 5.3 million and is expected to grow to 8 million over the next 20 years as new residents are drawn to the state for its jobs and famed outdoor lifestyle. "I can't build my way out of the current congestion, let alone the congestion that will come," Bhatt commented in a recent article in *Wired* magazine.<sup>2</sup>

"Hyperloop technology directly aligns with our goals of reducing the cost of transporting goods, of turning rural state highways into zero-death roads, and of decreasing congestion within Colorado's critical corridors," notes Bhatt.<sup>3</sup>

In October, under the umbrella of the RoadX program, Hyperloop One embarked on a nine-month-long feasibility study with Colorado DOT, AECOM, and several other transportation agencies in the state to assess potential routes from both a technical feasibility perspective and a commercial perspective. Working together, the organizations provided a framework to evaluate, implement, and finance new technologies like the hyperloop.

### Road to Tomorrow in Missouri

Missouri DOT was named one of the finalist teams in the Hyperloop One Global Challenge. In October 2017, Missouri DOT, the St. Louis Regional Chamber, the Kansas City Tech Council, the University of Missouri System, and the Missouri Innovation Center in Columbia, formed a public-private partnership called the Missouri Hyperloop Coalition to advance a hyperloop project connecting St. Louis and Kansas City via Columbia along the I-70 corridor.

The proposal envisioned using the I-70 corridor to facilitate travel between the two largest cities in the state in less than half an hour, effectively creating an economic superregion. On January 30, the Missouri Hyperloop Coalition announced an agreement to move forward on a seven- to nine-month feasibility study with the global engineering firm Black & Veatch and Virgin Hyperloop One.

Similar to Colorado DOT's RoadX program, Missouri DOT's Road to Tomorrow program assesses new business opportunities in innovative technologies for Missouri. Tom Blair, who leads the program in St. Louis, pulled together a team of members from St. Louis and Kansas City to work collaboratively to deliver Missouri DOT's proposal to the Global Challenge.

<sup>2</sup> [www.wired.com/2017/04/cities-crave-hyperloop-shiny-talk-cheap](http://www.wired.com/2017/04/cities-crave-hyperloop-shiny-talk-cheap).

<sup>3</sup> [www.codot.gov/news/2017-news/january/cdot-announces-colorado-selected-as-hyperloop-one-global-challenge-semifinalist](http://www.codot.gov/news/2017-news/january/cdot-announces-colorado-selected-as-hyperloop-one-global-challenge-semifinalist).



PHOTO: CAMBRA, OBSQUA, FLICKR

### Route Forward

These feasibility studies—along with several more to be announced in coming months—are the beginning of a journey to make the hyperloop a reality in the United States. As with any transportation or infrastructure project, careful and deliberate analysis of the route economics, environmental impacts, and other factors are required before the project can progress to subsequent phases.

If the outcome of these studies is favorable, the project then will move to a longer and more involved environmental impact study or assessment, in which the corridor and impacts on neighboring communities will be examined in greater detail. These studies provide the information required to allow a project sponsor to move forward with a project, to secure sufficient funding from private or public sources, and obtain approvals to begin construction. Compared with the permitting, approvals, and regulatory process, developing the technology to create the first new mode of transportation in more than 100 years almost looks easy.

According to the Rocky Mountain Hyperloop team, the technology could ease congestion on Colorado's highways.

Public agencies and private companies collaborated on a proposal to build a hyperloop project along the I-70 corridor in Missouri.



PHOTO: DOUG KERR, FLICKR