The fifth mode

The Hyperloop concept sees passenger-carrying pods whizzing through vacuum tubes at or near the speed of sound. Dubbed the "fifth mode" of transport behind air, sea, rail and road, it has attracted some of the best engineering and commercial talent in the world. **David Smith** explores the mad, and slightly chaotic, dash now under way to make it a reality

When entrepreneur Elon Musk proposed the Hyperloop in 2013, it generated enormous excitement. Rather than dismiss the concept of a 760mph tube transport system that could whisk passengers between LA and San Francisco in 30 minutes as a fantasy out of *Blade Runner*, the scientific community embraced it. Two companies – Hyperloop Transportation Technologies (HTT) and the confusingly similarly named Hyperloop Technologies (HT) – are competing to build the first complete system. Meanwhile, Musk's company SpaceX sponsored a design competition for a passenger transport capsule, or pod, that attracted 700 student teams from around the world, whittled down to 120 for the first round in January. These teams conform to Musk's vision of the process as "open-source" and collaborative, whereas HTT and HT are jealously guarding their ideas. All three – HTT, HT and SpaceX – are building test tracks this year to try out prototypes, so by the end of 2016 we will know far more about the Hyperloop's feasibility.

Meanwhile, the idea is firing imaginations in Europe. As CRI was going to press, the government of Slovakia announced that it had signed an agreement with HTT to explore the possibilities of a Vienna-Budapest-Bratislava Hyperloop network, although it is currently just a vision.

Had a less charismatic individual than Musk proposed the Hyperloop, the idea would likely never have gathered such momentum. But Musk's record as co-founder of SpaceX, Tesla Motors and PayPal lent him credibility. It helps, too, that he knows how to generate media attention. He came up with an enticing description of the Hyperloop as a "cross between a Concorde and a railgun and an air hockey table" and hailed it as a "fifth mode of transportation" that would never crash and would travel twice as fast as a jet. He even made it sound financially credible, comparing the estimated $7.5bn cost for a proposed San Francisco to LA route favourably with the estimated $60bn Californian high-speed rail development.

From late 2012 engineers from Tesla and SpaceX developed the idea and in August 2013, Musk published a 57-page white paper. The initial concept, since modified somewhat, involved sending 'pods' through a steel tube maintained at a partial vacuum. The elimination of air resistance would allow near supersonic speeds. Each capsule would float on a 0.5-to-1.3-millimetre layer of air provided under pressure to air-caster 'skis'. The aim was to avoid using magnetic levitation (Maglev), while still allowing speeds that wheels could not support. Linear induction motors along the tube would accelerate and decelerate the capsule. Musk called the concept a "fifth mode" of transport. It would not replace air travel altogether, but instead would be the preferred mode for travel between "high traffic city pairs" that are less than about 1500km (900 miles) apart. "Around that inflection point," he wrote, "I suspect that supersonic air travel ends up being faster and cheaper."

The white paper caused an instant stir. Within three weeks, JumpStartFund, a collaboration platform for entrepreneurs to crowdfund ideas, made the Hyperloop a flagship project and created a spin-off company to work on it. In October 2013 HTT was born. The remarkable thing about this company is that top talent flocked to work for it, and not for cash but for stock options.

"Once we put it on our internet platform, we were overwhelmed by the response," said HTT's chief executive Dirk Ahlborn. "We asked who wanted to work on it in exchange for stock options and we had 200 applications. We formed a team of 100 and today, we have more than 500 people and a backlog of another 600 applicants. We also work with some of world's best engineering companies, including Aecom and Oerlikon. They have the same contract as everyone else, offering man hours for stock options. Something like this has never been crowd-sourced before but it's working brilliantly," he said.

It is a misconception, he says, to see the Hyperloop as solely an engineering project. Although HTT's community contains high-level engineers from the likes of Boeing, NASA, Yahoo! and Airbus, it also includes social media experts, PR and marketing consultants, accountants, programmers, animators and video bloggers. The network is divided into working groups, including capsule design, cost analysis, route planning and high-speed internet. There are weekly discussions, but communication is mainly by email. 'Hyper' managers ensure all areas are addressed.

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At first, HTT was quite open about its progress, but it has become tight-lipped since the emergence of HT last year. Much of the initial work for HTT was done by UCLA students. They decided on a 'bubble strategy', loading the passenger pod, or 'bubble', into an outer shell inside the tube. The outer shell is equipped to handle high speeds and contains the air compressor. The UCLA students also proposed a robotic luggage-handling system so passengers would be free to pass through security and go shopping in the lobby. More recently, however, details about advances to the HTT designs have been withheld, though Ahlborn says the pods will be 3.75m wide to accommodate rows of three passengers. "We won't be giving our designs away. Why should we? Our competitors are not working with us so why give them any clues?"

HTT

According to Elon Musk, the Hyperloop would be the preferred mode for travel between "high traffic city pairs" that are less than 1500km apart

His remark betrays HTT's ambivalent attitude towards the new kid on the block, HT. (HT is the smaller company. It told CRI that it employs 129 people, of whom "75-plus" are engineers.) On the one hand, Ahlborn insists HTT wants HT to succeed because it is part of the same "movement". "The worst thing that could happen is they fail and give the Hyperloop a bad name," he said. But on the other hand, HTT are vexed by the way HT has barged in on its territory. Speaking at London's Construct/Disrupt engineering conference in October 2015, HTT's chief operating officer, Bibop Gresta, lamented that HT had adopted a name and logo so similar to HTT's. He described it as "weird".

Ahlborn believes his company's cashless start-up financial model is more sustainable. "Their way is different to ours. They have raised as much money as they can, spent it as fast as they can and grown as fast as they can," said Ahlborn. "We have had 600 investors reach out, but we felt our crowdsourcing methodology worked better if we didn't take the money at this stage. Despite our different approach, it's possible we'll have to work together in the future."

'Kitty Hawk' moment

At some point, however, HTT will have to raise money. For now, ideas come free in exchange for stocks, but it takes hard cash to build concrete and steel structures – and billions for an inter-city Hyperloop line. HTT is talking with private investors in Indonesia, China, Saudi Arabia, and the UAE, but no details have emerged. HTT also plans an IPO later this year. The 5-mile HTT test track will cost $150m, but the company has not disclosed how much it has raised.

HT has been open about its funding model since announcing its intention to develop a Hyperloop route between Los Angeles and Las Vegas back in February, 2015. The company had starting capital of $8.5m and quickly raised another $37m to fund research and the construction of a 1.9 mile test track in Nevada. In the past few months they have been busy raising another $80m.

Clearly, building a short test track is a different matter financially for HT from constructing the estimated $8bn 'real deal'. But both HTT and HT say the same thing: if they prove the concept on the test track, investment will flood in. Certainly, HT has high-level backing. Its chief executive is Rob Lloyd, former Cisco President of Sales and Development and the CTO and co-founder is former SpaceX engineer, Brogan Bambrogan. The half-billionaire entrepreneur Shervin Pishevar is chairman of the board.

HT has built some impressive test rigs to examine hardware in environments down to 1/1000 of atmospheric pressure. The largest piece of kit is the Big Tube, a 50-foot long carbon steel vessel weighing 70,000 lbs which validates the designs of tubes, orifices, vacuums, welds and automation.

HT says it is ready to build its 1.9-mile scaled-down 'Propulsion

HT

Artist's impression of a passenger pod, from Hyperloop Technologies, one of two companies pressing ahead with commercialising the concept

Open Air Test Facility' before the end of 2016, placing it neck and neck with HTT. According to Lloyd, this will be the company's 'Kitty Hawk' moment when it demonstrates Hyperloop at scale employing four main innovations - a low pressure tube which allows for less friction, the 'pod' itself, an electric propulsion system that uses the same principles as a rail gun, and a levitation system. Lloyd says the HT system only requires propulsion for 5% of the track. Once it reaches 750mph it can glide for 100 miles because of the lack of friction.

Meanwhile, HTT plans to begin construction on its 5-mile, passenger-ready Hyperloop in mid-2016. The intention is to build a short, fully functional Hyperloop in a town called Quay Valley, halfway between LA and San Francisco. Ahlborn expects the first passengers at the end of 2018, or beginning of 2019. But, as is typical in the Hyperloop universe, there are big uncertainties, including the fact that the town of Quay Valley does not yet exist. Plans for the town were proposed in 2007. It was sold asa sustainable community complete with schools, offices, shops and parks. The project was put on hold, but Gresta says developers will now break ground in 2016.

Elon Musk's own company, SpaceX, is building a third test track. At just a mile in length, it will be the shortest of the three when it opens near the company's HQ in Hawthorne, California, this summer. It will test the designs that impressed at the first stage of the competition at Texas A&M University, in January. This first stage was won by a team from Massachusetts Institute of Technology (MIT) ahead of more than 100 competing teams. The Delft University of Technology, from the Netherlands, was runner-up. MIT may have won, but 22 teams in all will test their pods, although SpaceX says a further 10 teams could still qualify. One curiosity of the competition is that the open-source student designs are available for the two commercial Hyperloop companies to study, but the reverse does not apply. In theory, there's nothing to stop HT or HTT copying the best student ideas, or poaching the brightest students.

The three test tracks have been criticised for being too small. The teams can test pods, tracks and vacuums, but they can't assess the Hyperloop at full throttle, and critics say there could be safety issues at near supersonic speeds. HTT says it could break land speed records even on a short track if passengers are not on board, but it won't be near 800mph.

Fact or fantasy?

Ahlborn expects to land a deal to build a full-scale Hyperloop within months. Having rejected LA to San Francisco as impractical, HTT is looking at 20 potential city pairs, many of them outside the US. "Our main target markets are Asia, Indonesia, the Middle East and Africa. In the Emirates all it takes is one sheikh to want Hyperloop and it will get done. We can demonstrate at Quay Valley that we have solved all the technical issues and it's just a question of refining our designs."

Ahlborn says he can estimate the cost of a full system accurately at around $18bn. "We know Aecom can build pylons to carry the tubes and we know how much they cost. We know Oerlikon can create low-pressure environments in the tubes and we know how much that costs, too. We can use solar, kinetic and wind power along the track to generate more energy than we use which we can sell to the grid. High-speed rail costs more as it requires high voltage power stations next to the track. Our technology is mainly inside the parts."

The HTT Hyperloop could be profitable within eight years, according to Ahlborn. "The most exciting part is not speed but affordability. Public transportation, especially rail, is heavily subsidised. We can become one of the first public transport systems that generates revenue and pays for itself." His claims about the affordability of Hyperloop have not been independently corroborated, however, and small test tracks won't provide enough evidence to support them. This is a problem with the Hyperloop: it is difficult to distinguish between hype and reality.

Musk started it. As well as his claims about near supersonic speed, he captured imaginations by saying Hyperloop could be used on Mars without rails. He also claimed the red planet's environment could be rendered amenable to humans by dropping thermonuclear bombs. Generations brought up on *Star Wars* have lapped it up. HTT's Gresta has continued in the same vein. He says the pylons could be vertical farms as well as carbon dioxide scrubbers, and the track will become the "longest billboard on the planet". Gresta also says the Hyperloop will be ten times safer than airline travel – a claim that is impossible to verify without high-speed tests.

Some have dismissed the cost projections as fantasy. In 2013 Musk claimed a line between LA and San Francisco, about 380 miles, could be built for $7.5bn, and tickets would cost around $20 one way. But Michael Anderson, a professor of agricultural and resource economics at University of California, Berkeley, insisted the figure would be more like $100bn. He told Al Jazeera that, leaving aside the cost of land purchases, the cost of building pipelines (between $5m and $6m a mile), the cost of building elevated viaducts, and the need for much straighter, and much higher-spec tracks would all conspire to make the scheme commercially unviable.

And yet, smart people and smart companies have jumped aboard. There is Aecom, a company employing more than 100,000 people and with revenues of $18bn last year. Oerlikon is another giant. The Swiss-based company supplied the vacuum parts for the Large Hadron Collider at CERN. Carl Brockmeyer, its Head of Business Development, says it already has pumps that would work for the Hyperloop.

"It's much easier than the Hadron Collider which tried to create a perfect vacuum like in outer space. We just need to optimise existing pumps by tweaking electronics and controls," he said. Technology costs have dropped as well, making the Hyperloop more affordable. "There are far more energy-efficient ways to create and hold a vacuum than a decade ago and it's much less expensive," Brockmeyer said. "So I am convinced it can be done in a viable, economic way."

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Working in exchange for stock options is unusual, however, and it troubled Oerlikon's lawyers at first. "They saw more risks than benefits and wanted to get rid of the deal, but we agreed in the end," he said. "But we're not in it for stocks. Of course, if we provide parts we would need to be paid."

Glory and excitement

For their part, the students are working only for glory and excitement as they hammer out the nitty gritty of pod design. And they have much smaller budgets – $100,000, in MIT's case. "We kept it as simple as possible so there's no passenger compartment," MIT team leader Philippe Kirschen, said. "We focused on three goals: it had to be safe and it had to be scalable so it could be applied to a full-scale system. And finally it had to be feasible so we can build it quickly on a budget."

The MIT team diverged from Musk's idea of using a cushion of air to levitate the pod. They've gone for Maglev technology. Magnets sit above a conducting plate, which in the first instance will be the SpaceX aluminium test track. Propulsion comes from induction motors built into the track. "These ideas were part of system called the Inductrack developed in San Diego by physicist Richard Post. We did a literature review and adapted the ideas."

MIT still has to finalise its design, but the prototype pod is likely to be 2.5 metres long and a metre wide, weigh 250 kilograms and travel up to 246 miles per hour. It is a bobsled-like structure with an aluminium frame and a carbon fibre shell. The electronics experts in the 30-strong MIT team are providing telemetry technology to aid orientation and braking. "We've designed the brakes to be fail-safe. Our hydraulic system uses powerful springs to clamp down on the rail and can provide deceleration at 2.5gs. It's fail-safe because if the hydraulic system malfunctions, the brakes close and the pod comes to a stop."

Most of the MIT team are research students but they are being allocated course credits for the work. The student team that came second in the January competition, from TU Delft in the Netherlands, is not so fortunate. Only ten of the 30 students in the Delft team are full-time. The rest are unpaid and have mostly taken a year off studies. "It's a gamble, but it's a great experience to work on something of this scale," said Delft team captain Tim Houter. "Everyone is passionate about it as we believe it could become a reality. In the past 40 years we've barely seen any innovation in transportation. We still spend billions travelling slowly and using unnecessary energy. We don't see the competition as an end in itself, but as a warm-up for the real thing."

The Delft team has proposed building a Hyperloop between Amsterdam and Paris. Like the MIT group, they are using magnetic levitation, although they opted for frictionless magnetic brakes whereas MIT uses friction brakes. The Delft pod will be tested in the Netherlands prior to the summer SpaceX heat by using rotating discs to simulate the movement of tracks under pods. Like MIT's Philippe Kirschen, Houter gives a confident endorsement of his team's work. "Because our system uses magnets that are permanent and always magnetic for levitation and stabilisation there's no risk of magnets failing," he said.

Houter has thought carefully about common objections to the Hyperloop. One myth he is keen to rebuff is that travelling in a window-less pod would feel claustrophobic. "Normal trains go through tunnels for more than 30 minutes, and we use metros in which almost no light is visible. We travel in planes for more than 10 hours at 12km height with tiny windows. So why wouldn't we go in a capsule for a mere 30 minutes? Also, we could use high-resolution screens on all sides to display a 360° view of the surroundings. Extra attention will also be paid to creating spacious and comfortable designs."

Another objection is that Hyperloops are unnecessary because airplanes already travel at 1,000km/h. But Houter points out that a lot of the travel time on a plane journey is spent at airports. "Checking in, going through customs, boarding, taxiing and taking off all take a lot of time," he said. "And this process is repeated at the destination airport. The Hyperloop can be as convenient as a metro. People get to the station, go through a brief security check, and board the next Hyperloop. Capsules could leave every one or two minutes."

The students' confidence is inspiring, but have they caught the bug of bigging up the Hyperloop? A fully functioning, commercially viable system looks to be at least a decade away, if ever. By the end of 2016, after tests from all three groups involved, we will know a lot more than we do now. In the meantime, what can't fail to impress is the sheer scale of the resources and brainpower the concept is attracting from so many quarters, and much of it for free. ❑