Montgomery de Luna

# University of Waterloo Hyperloop:

## *Precedence for the "Unprecedented"*

ARCH 686
Competitions Elective
Final Essay Submission
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## *Introduction*

The University of Waterloo Hyperloop team, *Waterloop*, entered the international SpaceX Hyperloop Pod Design Competition 1 on January 27-29, 2017, revealing 1 of 30 of the world's first Hyperloop vehicle prototypes displayed and tested at the event (Figure 1). An Hyperloop is a theoretical, next-generation, high-speed transit system, first proposed by Elon Musk in 2013[1], that would rapidly transport passengers and freight in compact capsules through a near-vacuum, tube-like track, reaching high-speeds up to 1,220 km/h, or Mach 0.99[2]. Although Musk describes the system as, "truly a new mode of transport – a fifth mode after planes, trains, cars and boats," [3] various permutations of the same idea have been around since at least the beginning of the nineteenth century. The following comparisons will demonstrate the influences throughout history which have had an impact on the concept of the Hyperloop and its ultimate materialization in the Waterloop team's built functional prototype. Firstly, investigating the lineage of this transportation technology "type". Secondly, how the team's prototype built on existing technologies to create a new, experimental, and theoretical technology. Finally, how the design of the Waterloop team's vehicle took departed from existing transportation technology by taking influences from science fiction.

*Figure 1 Waterloop's Hyperloop pod prototype Goose I on display at the SpaceX Hyperloop Pod Design Competition I in front of the SpaceX Hyperloop test track (in white)*

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[1] "Hyperloop Alpha" SpaceX Hyperloop, accessed April 22,2017. http://www.spacex.com/sites/spacex/files/hyperloop_alpha.pdf
[2] SpaceX Hyperloop, "Hyperloop Alpha."
[3] SpaceX Hyperloop, "Hyperloop Alpha."

As a nascent technology, the Hyperloop is a new take on an old idea; presenting new constraints, new goals, and new existing technologies to work with. Although the goals of a Hyperloop are quite clear from Elon Musk's alpha document—what is not clear is how exactly this will be achieved. Although there exists a long lineage of engineering science informing the development of the Hyperloop, the reality is that no one has ever operated a near-sonic vehicle levitating in a low-pressure tube before, and therefore the use of prototype vehicles is necessary to learn about the behavior of the vehicle in the low-pressure track and the specific physics of this scenario. Major areas of research that have yet to be completed include the behavior of magnetic or pneumatic levitation in a low pressure environment at near-sonic speeds, the dampening of vibrations, the behavior of Eddy current braking in this application, overcoming the Kantrowitz limit, and failure scenarios, as well as many more criteria. Therefore, the intent of the competition, which saw over 1,200 entries from around the world[4], was to rapidly source many different technological strategies simultaneously, and select the best of a diverse number of options for half-scale physical tests. In the competition each of the 30 teams invited to the final round presented drastically different strategies for achieving the criteria of an Hyperloop design, aggregating centuries of research, design, and technology, in different ways to create 30 unique prototype vehicles.

### *Evolution of the Pneumatic Transportation Technology Type*

The first proposals of pneumatic transit systems go back as early as George Medhurst's relatively unknown 1799 freight proposal, and his 1812 passenger proposal for transit using air pistons.[5] More popular iterations of pneumatic transit systems came later, such as the Crystal Palace Pneumatic Railway, and the Beach Pneumatic Transit System;[6] which both proposed the movement of air to provide propulsion to the vehicle.[7] A pneumatic railway was later briefly realized by Thomas Webster Rammell in the Crystal Palace Park from the Sydham Entrance to

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[4] Stacy Liberatore, "The Hyperloop is go! SpaceX tests student pod designs that could make Elon Musk's vision for the future of transport a reality," *The Daily Mail*, Jan 31, 2017, http://www.dailymail.co.uk/sciencetech/article-4173812/Elon-Musk-reveals-winners-Hyperloop-pod-contest.html.

[5] R. A. Buchanan, "The Atmospheric Railway of I.K. Brunel," *Social Studies of Science* 22, no. 2, (1992): 231–2.

[6] William Wahl, *Iconographic Encyclopedia of the Arts and Sciences: Constructive arts and building engineering Volume 5* (Philadelphia: Iconographic Publishing Company, 1889), 233.

[7] J. E. Connor, "The Crystal Palace Pneumatic Tube Railway". *The London Railway Record* 37, (2003).

the Armoury[8] for 2 months in 1864[9] in London, based on Sir Rowland Hill's initial proposition in 1855.[10]

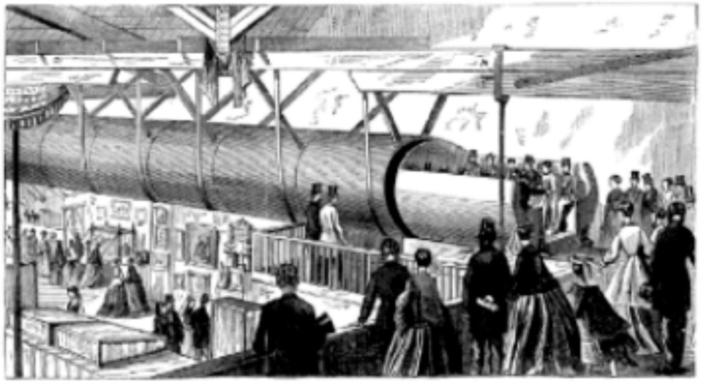

*Figure 2 "Beach's American Institute Fair exhibit 1867"*

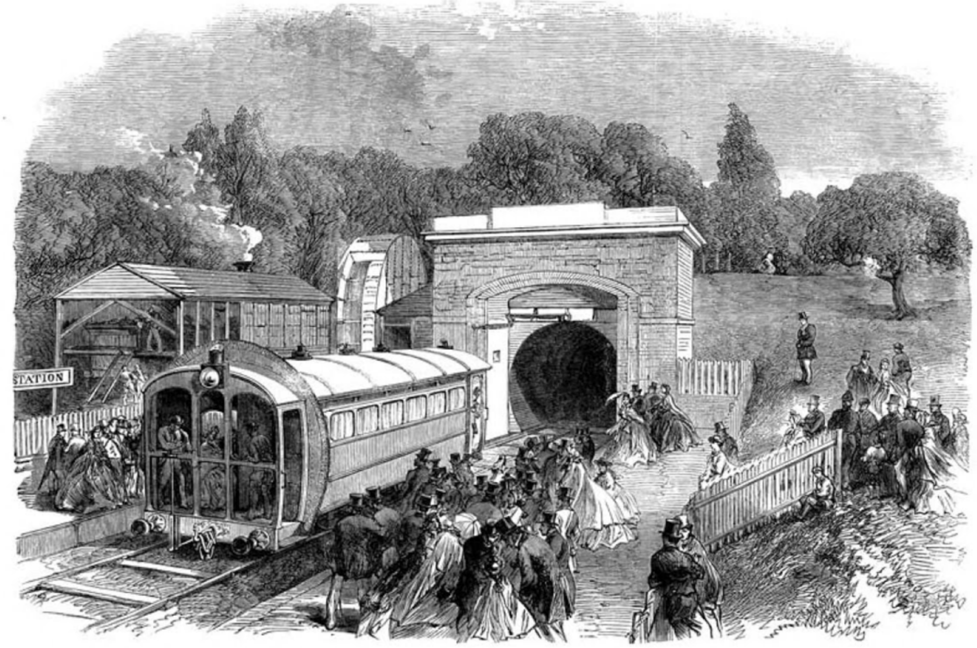

*Figure 3 The Crystal Palace Pneumatic Railway*

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[8] Wahl, *Iconographic Encyclopedia of the Arts and Sciences: Constructive arts and building engineering Volume 5*, 233.
[9] John Wade, *The Ingenious Victorians: Weird and Wonderful Ideas from the Age of Innovation*. (South Yorkshire, England, Pen and Sword, 2016), 218.
[10] Frank Moore Colby and Harry Thurston Peck, *The International Year Book*. (New York City, Dodd, Mead & Company, 1899).

While this method of propulsion by air current is feasible at lower speeds, Musk quickly dispels the strategy in the Hyperloop alpha document, explaining that in order to achieve his assigned target of near sonic speeds, the amount of friction created by a 350 mile long column of air would be so high that it would be, "impossible for all practical purposes."[11] Musk therefore, proposes to deviate from this history and suggests instead a strategy previously proposed by Evacuated Tube Transport Technologies (ET3)—evacuated air tubes that provide extremely low air resistance.[12] The ET3 Global Alliance proposal targets both higher speeds and a more compact form factor than the Hyperloop,[13] making the project both more ambitious, and further away from realization. Achieving a vacuum state for an intercity track is one of the biggest challenges of any evacuated tube transit proposal, as any minor leak, faulty seal, or structural weakness could compromise the entirety of the vacuum. Currently the largest vacuum chamber in the world is NASA's Space Simulation Vacuum Chamber at 22,653 $m^3$,[14] (the second largest is the SpaceX competition test track) whereas the 5 foot diameter ET3 track, at a comparable distance to the Hyperloop of 350 miles, would require a 4,110,000 $m^3$ vacuum. In order to side-step the issues of maintaining a complete vacuum for such a large volume, the Hyperloop proposal increases the air density of the ET3 by roughly 1,000 times,[15] removing the most imposing obstacle in the development of the technology by specifying an air pressure that could overcome minor pressure leaks with standard commercial air pumps.[16]

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[11] SpaceX Hyperloop, "Hyperloop Alpha."

[12] SpaceX Hyperloop, "Hyperloop Alpha."

[13] "Who Needs Hyperloop? This Guy Is Building Something Bigger," Mashable, accessed April 22, 2017. http://mashable.com/2013/08/25/hyperloop-daryl-oster/#OycdNsO34ZqO

[14] "Space Power Facility," NASA, accessed April 22, 2017. https://www.grc.nasa.gov/WWW/Facilities/ext/spf/index.html

[15] Mashable, "Who Needs Hyperloop? This Guy Is Building Something Bigger."

[16] SpaceX Hyperloop, "Hyperloop Alpha."

*Figure 4 The largest vacuum chamber in the world, NASA's Space Simulation Vacuum Chamber*

*Figure 5 The second largest vacuum chamber in the world, the SpaceX Hyperloop test track used to test vehicles in Competition 1*

*Figure 6 Track proposal by ET3 with a vacuum state 1,000 times less dense than the SpaceX track. Note the large obstruction to track sectional area.*

This compromise on the air pressure of the track environment introduces a new problem to the technology, called the Kantrowitz Limit. Occuring near sonic speeds, it is the maximum speed at which an obstruction in a tube can travel, for the sectional tube area to obstruction area ratio, before the obstruction begins to act as a piston, moving the air column, rather than moving through the air.[17] Although the diameter of the tube could be increased, this would not only increase the volume of air that would need to be evacuated, it also would increase the cost of construction drastically, as the cumulative costs of the larger tube, increased structure, and increased pump demands are compounded across the full length of each track built. Therefore, in order to counteract the resultant increase in drag, Musk proposes an on-board air compressor to relieve any additional high-pressure build up in front of the vehicle.[18]

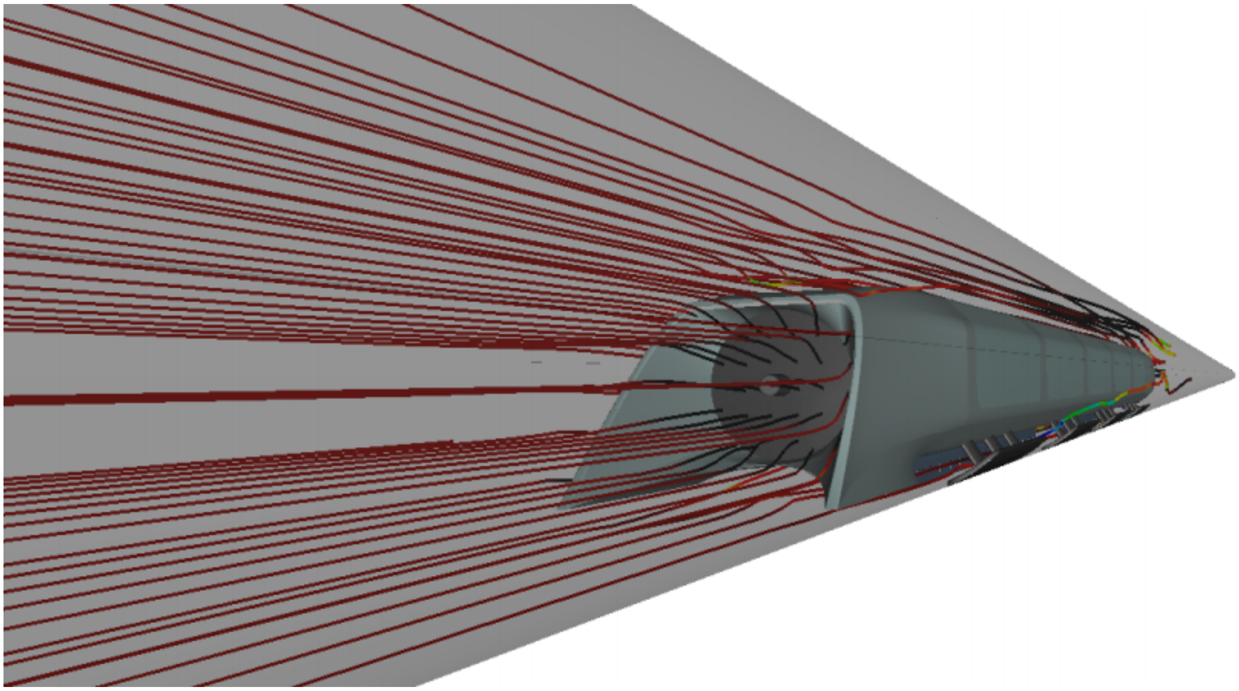

*Figure 7 SpaceX diagram: "Streamlines for capsule traveling at high subsonic velocities inside Hyperloop." Illustrates how the air compressor would relieve the pressure build-up causing the Kantrowitz limit*

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[17] SpaceX Hyperloop, "Hyperloop Alpha."
[18] SpaceX Hyperloop, "Hyperloop Alpha."

These three changes are the largest innovations to the pneumatic transportation system type from George Medhurst's 1799 proposal, up to Elon Musk's in 2013: the shift from pneumatic propulsion, to an evacuated air tube such that speeds and efficiency can be increased; the change from a near-vacuum state to a low-pressure environment in the tube to increase the feasibility of track design; and the introduction of an on-board air compressor to counteract the Kantrowitz limit.

### *Implementation of Air Caster Technology*

The specifics of how Hyperloop technology works, and even which systems are used to accomplish these goals, have yet to be determined. One major differentiation in the design of the vehicle pods is the choice between magnetic levitation and air bearing suspension systems. Although magnetic levitation has become the industry standard for low-friction vehicle suspension such as in maglev trains, the technology comes with many caveats that make it an unideal precedent for the Hyperloop. Firstly, a tremendous amount of weight is added to the vehicle by onboarding the electromagnets, and the large battery arrays necessary to power the magnets further increases the weight of the vehicle because of the amount of power the electromagnets require. This means it would also necessitate either increased charging time and battery requirements in the full scale vehicle, or an electrified line running along the track to power the vehicle—in addition to the metal plate required to provide the surface for the vehicle to levitate from on the track. The combined effects make it, more expensive, heavier, and harder to maintain than ideal; and the cost of adding thick metal plating and possibly an additional power line along the entire length of the track would increase the system's costs dramatically.

For these reasons, the Waterloop team pursued an air bearing levitation system instead for the built half-scale prototype vehicle entered in the competition, the "*Goose I*". This created a system that is simpler, lighter, cheaper, and easier to manufacture and maintain. The components of the levitation system include: air bearings (the diaphragm which disperses high-pressure air), air casters (the assembly which holds the bearing), air tubes, regulators, fittings, and air tanks. Air bearings are typically used in industrial applications to move heavy objects effortlessly by levitating up to 1,000 lbs per 12" air bearing.[19] The closest analogues to this implementation would be the few attempted hover-train projects around the world: the 1965-1977 French Aérotrain[20] which was briefly operational, the canceled Tracked Hovercraft[21] project of England, the cancelled US Department of Transportation's 1960 and 1970s "Tracked Air Cushion Vehicle"[22] prototypes, the Narita Airport shuttle which was shut down in 2012,[23] and the Dorfbahn Serfaus,[24] a cable propelled shuttle in the small Austrian village of Serfaus, which is possibly the only tracked pneumatically suspended vehicle still operational. Despite the apparent similarities of these vehicles, the largest difference between them and the Waterloop prototype is the low-pressure environment of the Hyperloop track, and the near sonic speeds of the Hyperloop vehicle. Both of these conditions mean the air will behave very differently and therefore further analysis, prototypes, and testing will be necessary, if obstacles such as the intense vibrations that were observed at the SpaceX competition are to be overcome.

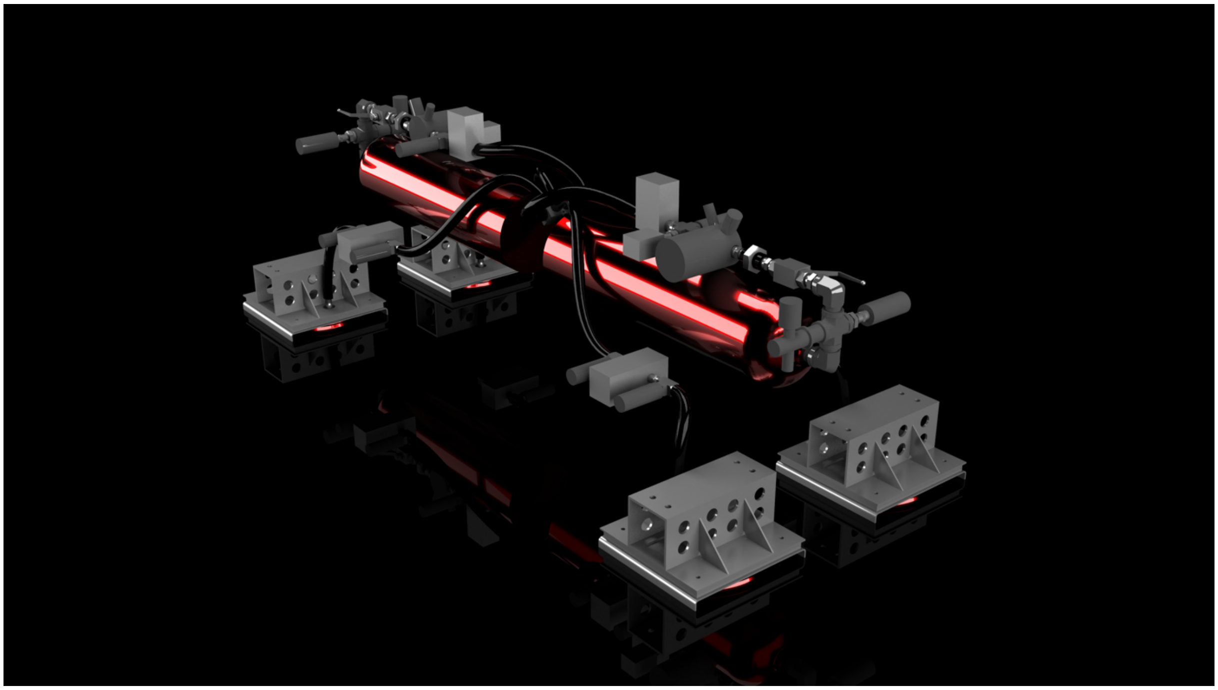

*Figure 8 Render of Waterloop team's Hyperloop pod levitation system*

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[19] "Air Bearing & Caster Systems," Hovair, accessed April 22, 2017, http://hovair.com/air-bearing-info/air-bearing-systems.htm.
[20] Jacob Meunier, *On the fast track: French railway modernization and the origins of the TGV, 1944-1983*. (Westport, Connecticut, Greenwood Publishing Group, 2002), 109.
[21] Timothy Johnson, "Science and the Paymasters," *New Scientist* 50, no. 757 (1971): 756.
[22] John Volpe, "Streamliners Without Wheels," *Popular Science* 195, no. 6 (1969): 55.
[23] "A new communication passage is completed at Narita Airport," *Nihon Keizai Shimbun (Tokyo)*, Sept 21, 2013, http://www.nikkei.com/article/DGXNASDG2004H_Q3A920C1CC1000/
[24] "Dorfbahn Serfaus," Funimag, accessed April 22, 2017, http://www.funimag.com/funimag13/serfaus01.htm.

*Figure 9 Tracked Hovercraft*

*Figure 10 Aerotrain*

*Figure 11 Dorfbahn Serfaus*

### *Precedents of the Prototype Shell*

The design of the prototype shell structure was an iterative process governed by the functional requirements of the shell: a lightweight, protective fuselage, that can withstand all load conditions in the prototype testing at the SpaceX test facility during the competition. In the case of the tests performed at the competition, the three control scenarios would be the acceleration/deceleration cases, a "burst" test of high-pressure air applied to the exterior of the fuselage, and the vibrations the shell would be subjected to in-flight. Each of these criteria was specific to the speed of the test runs performed on the Hyperloop test track and the design and behaviour of the vehicle itself, therefore, fulfilling these criteria was an iterative process of determining the loading scenarios, drafting a design, performing computer analysis, refining the design, constructing physical prototypes, performing physical tests, and revising the design accordingly. The Waterloop pod is designed for a cruising speed of 550km/h, with a maximum acceleration and deceleration within the range of human comfort at 1.5g. Using this criteria, the amount of stress, strain, and deflection, could be determined in computer modelling on each part of the vehicle to determine whether the shell would be strong enough—the design goal being to make the shell as lightweight as possible before risk structural failure.

One of the first material considerations for the shell of the vehicle was carbon fibre—known for its high tensile strength, heat resistance, low weight, and high stiffness amongst other criteria, the material is a logical option for the construction of the fuselage, as demonstrated by the precedent set by previous Waterloo engineering teams such as the university's WatSub submarine team.[25] However, carbon fibre comes with several complications: extremely high costs, and very difficult workability. For this reason, the first inspiration for the design came instead from contemporary aircraft construction, such as the Airbus. Aircraft typically have a series of vertical ribs, connected by horizontal stringers and a riveted aluminum skin that takes part of the shear load experienced by the fuselage.[26] The first shell design for the Waterloop prototype featured a similar rib system at 1 ½ foot intervals made from bent 1 inch aluminum square tubing, horizontal connections, and a riveted aluminum skin. A set of construction drawings was put together and the contractor

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[25] "Composites 101 Workshop," Watsub, accessed April 22, 2017, https://watsub.ca/composites-101/.

[26] David Peery, *Aircraft structures*. (Mineola, New York, Courier Corporation, 2011), 412.

arranged, however, despite passing the initial strength analysis, the estimated weight of this iteration came in at 93 pounds. While relatively lightweight, speed targets for the team required decreasing the weight of all systems, and a new design was necessary.

*Figure 12 Airbus fuselage structure*

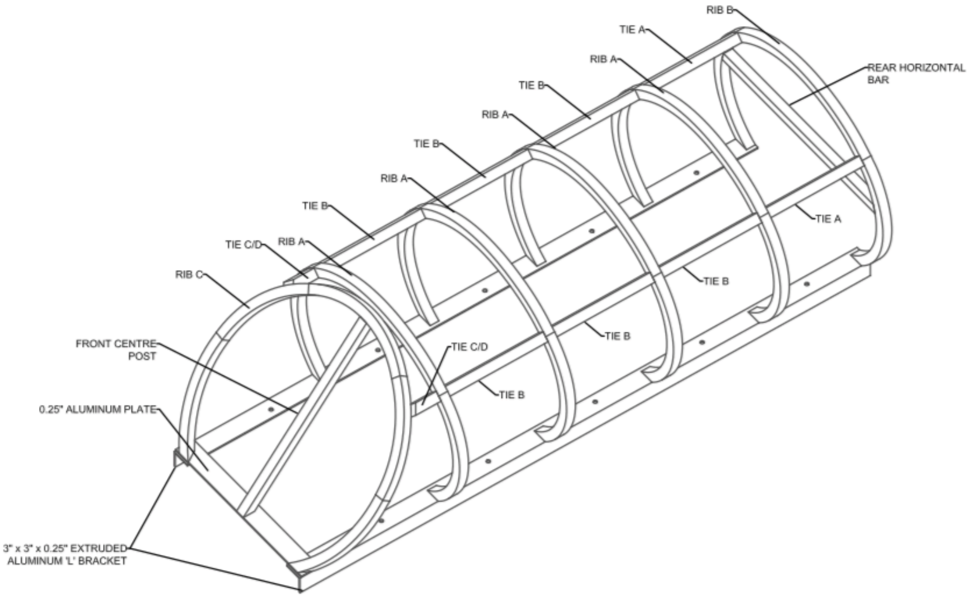

*Figure 13 Excerpt from the fabrication drawings of the first complete iteration of the pod shell design*

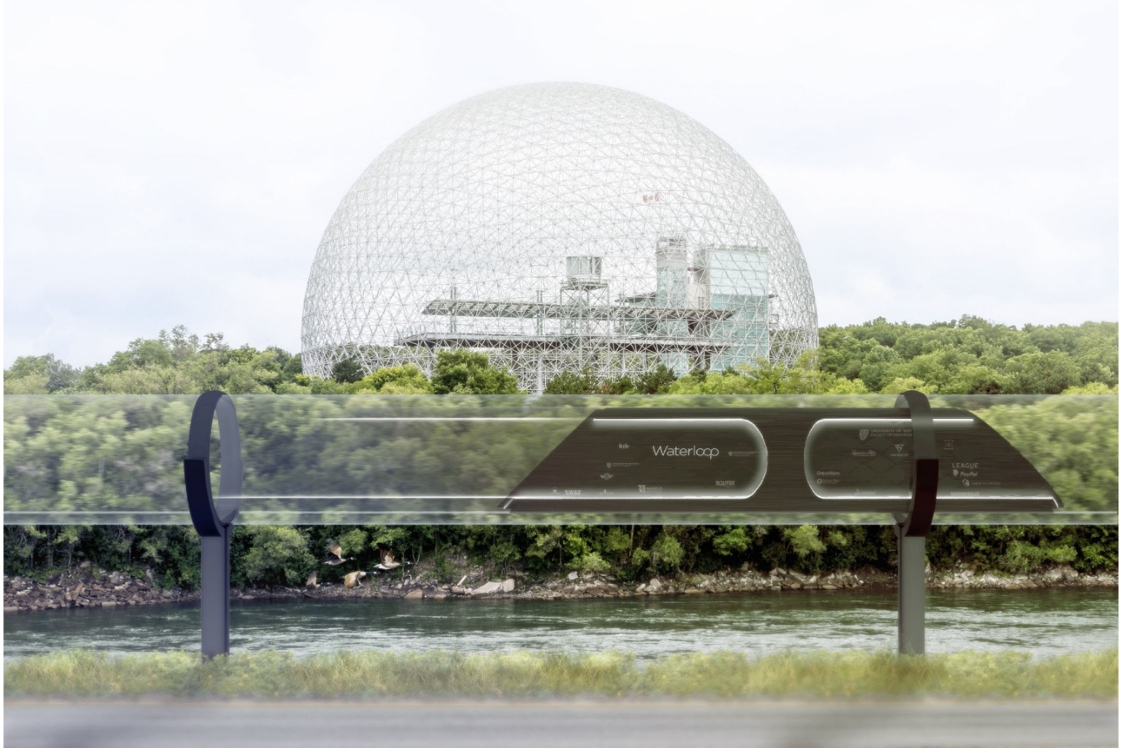

*Figure 14 Hyperloop pod pictured in front of structural design inspiration for the second shell iteration, Buckminster Fuller's Biosphere in Montreal*

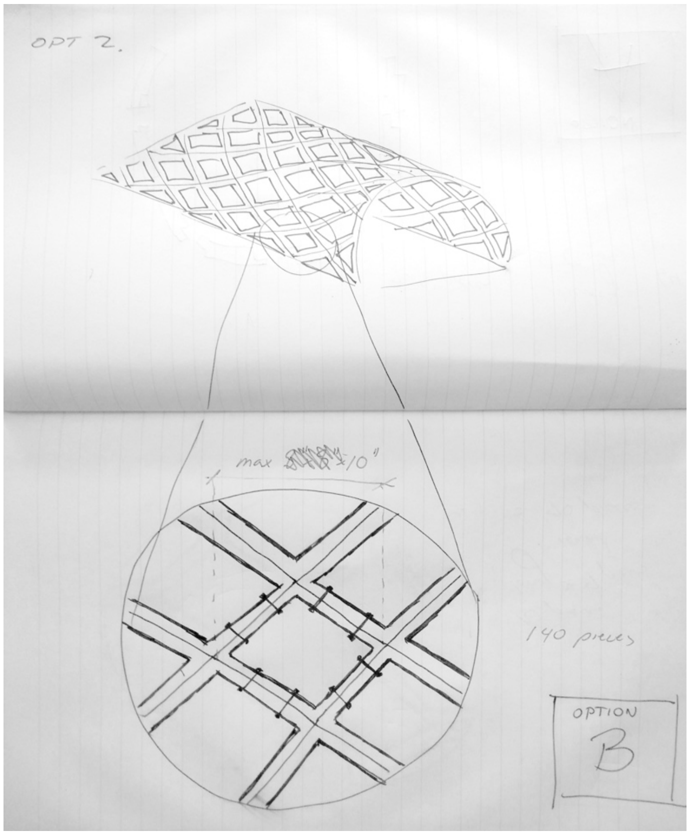

*Figure 15 Early concept sketch of a modular geodetic structure shell*

The second design iteration came when a new 3D printing sponsor joined the team, opening up new possibilities to use rapid fabrication techniques to make custom and complex geometry out of materials such as carbon fibre reinforced plastics, 3D-printed metals, and cast duplicates of ABS (Acrylonitrile-Butadiene-Styrene) printed plastics. A new series of concepts made of modular parts to create a diagrid structure were inspired by Buckminster Fuller's Biosphere dome in Montreal. Two strategies were developed: either a set of tubes, connectors, and infill pieces, or structural diamond panels connected by connector pieces at each corner. The diagrid structure had the advantage of aligning the structural members to the forces experienced during acceleration and deceleration—whereas the ribbed design, supported from the base, would experience loads almost entirely laterally, giving the ribs the tendency to "tip", creating a shear load in the aluminum skin. Ultimately, these concepts were abandoned as it created too much workload for the 3D printers and the high-strength materials requested would be too expensive to make the concept feasible, and so a new option needed to be developed.

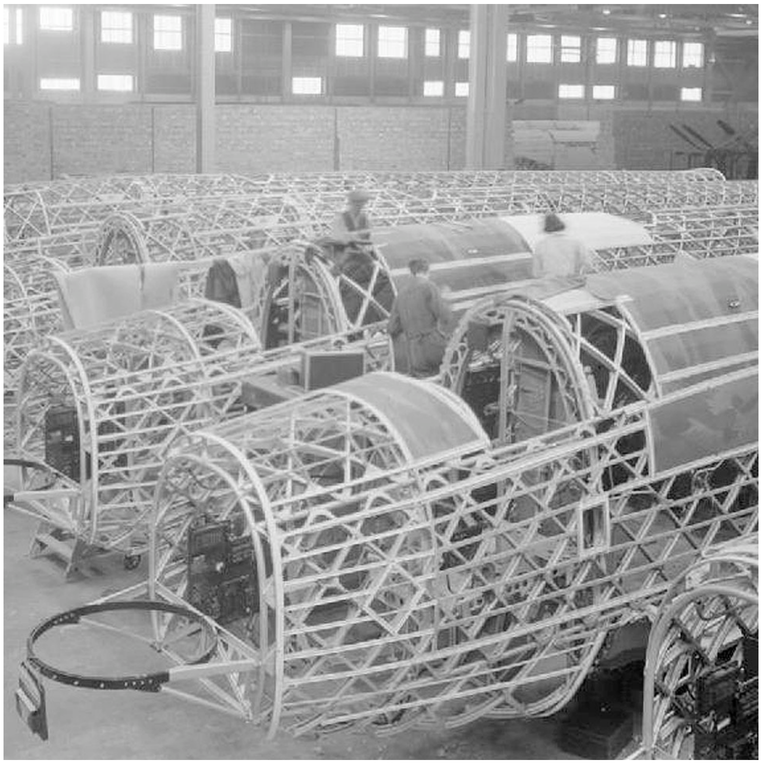

*Figure 16 Geodetic airframes under construction*

The lessons learned from the geodetic design studies were then implemented in the next version of the design. The structure would focus on cross-bracing to relate to the loading scenario and eliminate redundancies. Geodetic aircraft design was then used as an inspiration, which had the advantage of handling all of the shear loads within the structural members themselves: the torsional loads of the two-spiralling helices forming the basket weave of the geodetic frame cancel each other out. [27] The resultant structure was relatively light and strong, and left the interior of the plane free of structure. At the time, the geodetic airframes had the disadvantage of being difficult to construct—they had a complex structure to design, many unique parts, and required more additional labour. However, with the advantage of contemporary 3D modelling programs such as Rhinoceros, and rapid fabricating techniques provided by our 3D printing and laser-cutting contractors, the Waterloop team was not bound by this constraint. The result was a simplified geodetic structure, lasercut out of aluminum, connected by 3D-printed parts, with a thin lasercut aluminum skin, machine-rolled, and affixed to the 3D-printed connectors. The design was punctuated by diamond windows that allowed for visual inspection of the other systems for troubleshooting purposes, and relief airflow to prevent pressure build-ups on the skin. The diamond windows and front and rear panels were CNC milled out of bulletproof Lexan to ensure any loads wouldn't shatter the material, and the corners of the aluminum skin were filleted at the openings to distribute stresses around the corners. The design was analyzed and found to have negligible deflection under 2.4g of force (a safety factor of 0.9g more than the design acceleration), and the connectors were analyzed for the local forces applied to each piece. Each connector was designed such that the load would by applied in the strong xy-axes of the piece—the z-axis of the print being weaker because of the layering technique that builds up each part during the printing process. Despite the fact that the parts held up to the forces subjected to them in analysis, when the printed parts underwent physical stress testing, they occasionally exhibited problems of delamination between printed layers, even when the weak axis was not directly loaded. Although many options still remained: reprint the parts out of stronger materials, printing using liquid resin 3D-printing, reinforcing the parts with an application of epoxy, or carbon fibre, or casting the parts out of a stronger material—by this phase of production, the competition was only months away and a more rapid and reliable solution was needed. As a

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[27] "Geodetic Aircraft Design," Barnes Wallis Foundation, accessed April 22, 2017, http://www.barneswallisfoundation.co.uk/life-and-work/geodetic-aircraft-design/.

result, the frame would be welded together, an option previously not pursued because of the cost, the complexity of the design, and a large increase in dimensional tolerance. The 3D printed connectors ultimately resolved locating each structural member within the complex geometry by allowing the assembly of a dry-fit with millimeter precision before welding, drastically improving the resultant tolerances. Unfortunately, the pull created by the cooling welds resulted in an unavoidable movement that decreased the tolerances of the construction from a fraction of a millimeter of the initial design, to almost 15mm.

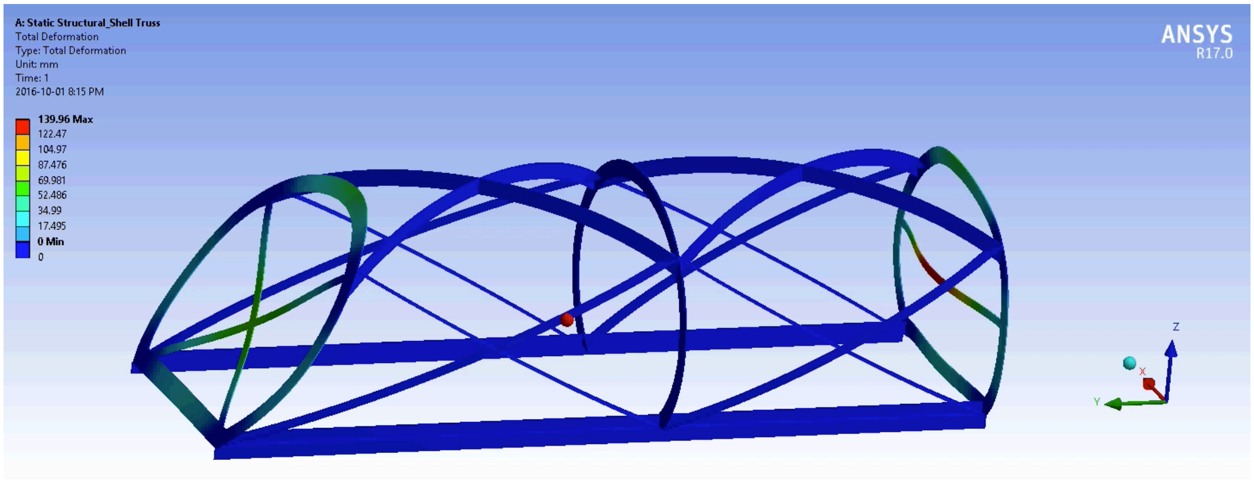

*Figure 17 Deformation analysis of inwards forces of 90N*

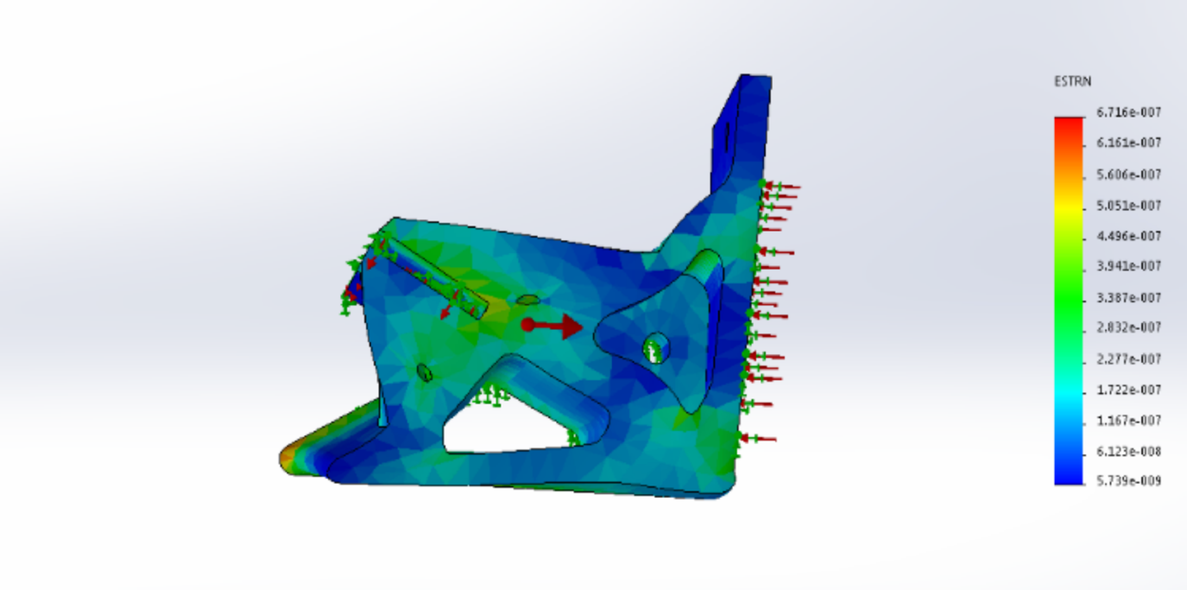

*Figure 18 Deformation from the pulling pressure of 200000 Pascals (safety factor of 2) from diagonal truss, and 300000 pascals (safety factor of 2) from the vertical structural member of the 3D-printed connector*

### *Precedents of the Concept Vehicle Design*

As a nascent technology in a stage of speculative development, funded entirely by investors and sponsors, the design of the public experience of the Hyperloop is a key part of the success of the technology. This made design of the experience a crucial part of financing team Waterloop, as well as setting the precedent for public expectations of design excellence for the future of urban infrastructure. At the time Waterloop released the first renderings of the *Goose X* concept vehicle (the full scale passenger vehicle concept design), only three prominent concept designs existed for the Hyperloop pods. The designs of each were heavily approximated artistic renderings—they had little realism to the technology being developed by the companies producing them, and the designs themselves looked closer to retro-futurist attempts at capturing space age visualizations of the 1960s and 1970s, rather than contemporary design. Waterloop was situated in a position in which it could influence the future path of Hyperloop design by bringing these concepts to the next level of realism.

The primary design goals of the *Goose X* concept vehicle were to introduce a level of realism to the passenger vehicle concepts, to create a decisive break from past transportation technology design, and to use design to create an exciting public experience. The interior dimension of the vehicle is intrinsically at odds with the economics of a full-scale Hyperloop—the greater the interior dimension, the greater the vehicle dimension, the lower the Kantrowitz limit, the greater the track tube diameter, and therefore, the more expensive the track. Musk cites an ambitiously small passenger vehicle dimension, as small as 1.35m by 1.1m, and a mixed passenger cargo vehicle as large as 2m by 2m.[28] Therefore, any ability to counteract the potential claustrophobia of the vehicle would be valuable to the design.

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[28] SpaceX Hyperloop, "Hyperloop Alpha."

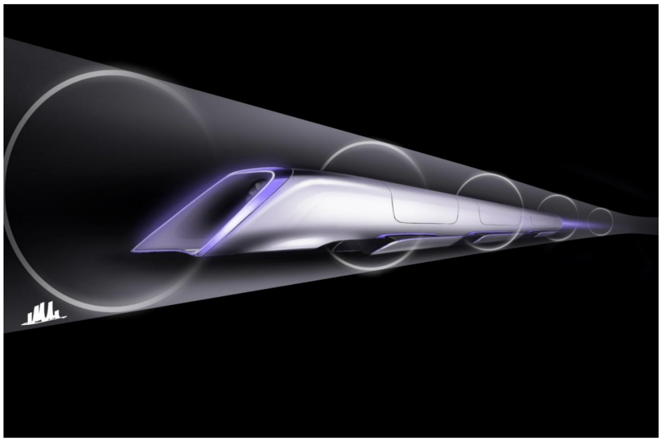

*Figure 19 SpaceX visualization of Hyperloop Pod*

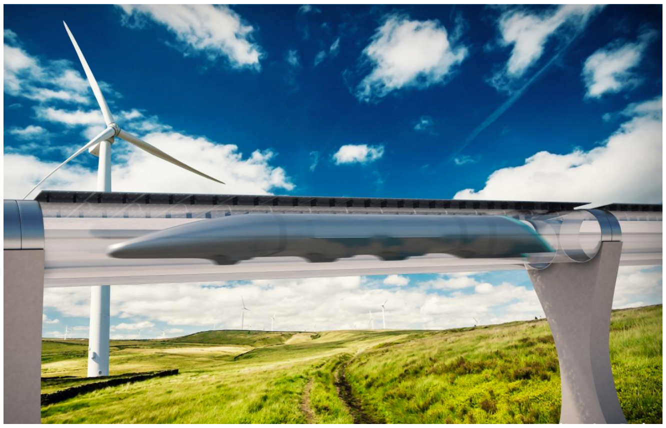

*Figure 20 Hyperloop Transportation Technologies rendering of Hyperloop pod*

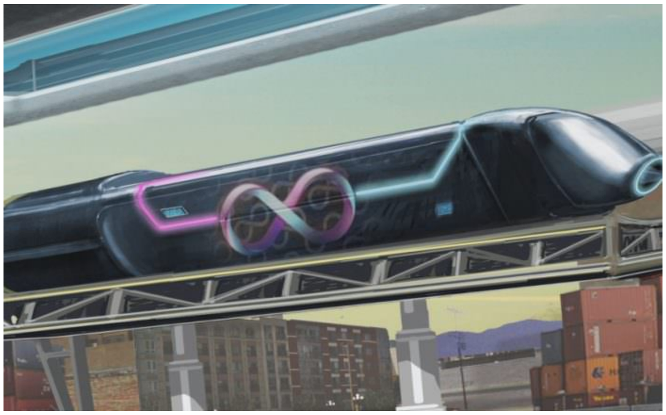

*Figure 21 Hyperloop One concept art of a Hyperloop pod*

To break from the unremarkable passenger interiors of vehicles such as the Boeing 747, a more inspiring precedent was chosen: the Millennium Falcon cockpit (which was itself was inspired by the B-29 Bomber[29]). The intention was to simultaneously evoke a sci-fi, high-tech, future; as well as to give the passenger the sense of adventure and liberty of being in the cockpit of the vehicle, rather than the cargo bay. As a result, the helical structure of the *Goose I* prototype vehicle was recalled on the interior of the vehicle, with diamond shaped screens and mirrors aligning to the lines of the underlying structural members, creating an exciting helical environment in the interior. The cylindrical interior geometry both maximizes the amount of sectional area the vehicle can fill of the tube track, as well as the necessity of a circular cross section of the pressurized vessel to remove any stress points at corners. The white colour, use of accent lighting, interior mirrors, and screens that could display exterior environments or abstract patterns, were all used to create an interior that felt as large as possible; with luggage storage strictly under seats or in a separate cargo compartment—both to increase passenger space and reduce the likelihood of injuries due to luggage falling out of overhead compartments.

*Figure 22 Passenger interior of a Boeing 747*

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[29] "Did you know that the Millennium Falcon's cockpit was inspired by the WWII B-29 Superfortress bomber?," The Aviationist, accessed April 22, 2017, https://theaviationist.com/2015/12/15/millennium-falcon-b-29-cockpit/.

*Figure 23 Cockpit of the B-29 Superfortress Bomber*

*Figure 24 Cockpit of the Millennium Falcon*

*Figure 25 Passenger compartment of the Waterloop Goose X concept Hyperloop vehicle*

The exterior of the vehicle intentionally broke away from the long history of white passenger aircraft, instead selecting a matte-black exterior, which similarly recalled the diamond-pattern of the interior and the *Goose I* half-scale prototype vehicle. Futuristic cities envisioned by Harvey Wiley Corbett and Hugh Ferriss, inspired the ambition of integrating track infrastructure into cities, rather than detracting from them. The oppressive conditions of highway overpasses were to be avoided, and small design cues were take from science fiction work such as Tron Legacy, by creating track infrastructure the stood on elegant but simple and effective pre-fabricated piers. The supports suggest an appearance of illuminated checkpoints, with a lit-up structural ring fixture mounted on a double concrete pylon, which forms to cup the track.

*Figure 26 View of highway overpasses in Tokyo*

*Figure 27 Daytime view of the Waterloop Goose X passing Toronto – clear tubes would only be used at low speeds within the city, closer to 1 atmospheric pressure, rather than the near vacuum state that would necessitate a steel tube.*

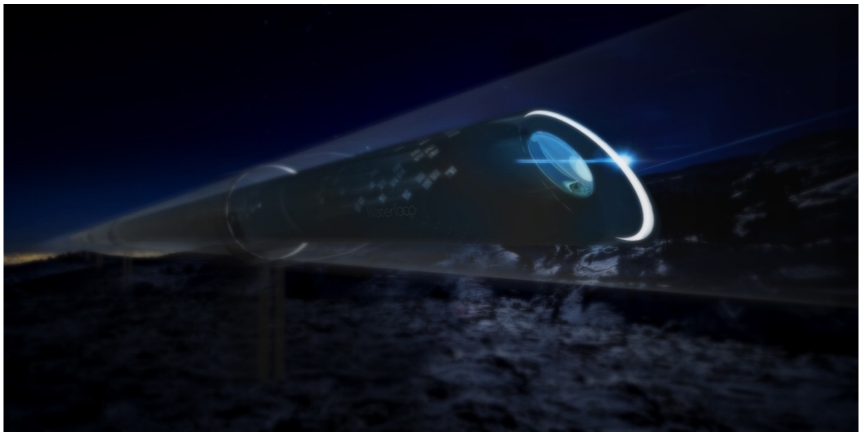

*Figure 28 Night time view of illuminated track rings with an early train-like iteration of Goose X*

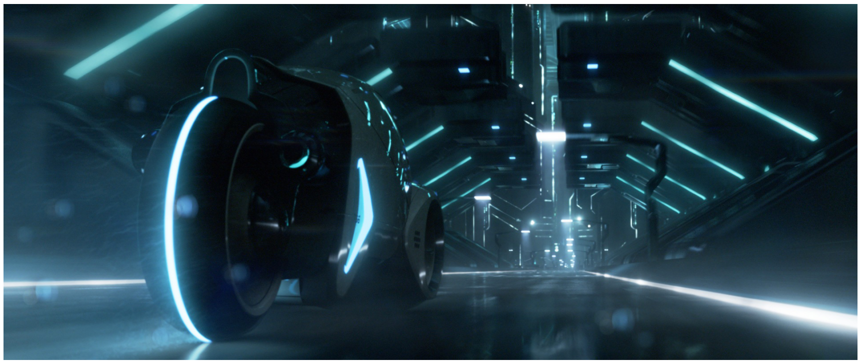

*Figure 29 View of "lightcycle" and infrastructure in Tron Legacy*

## *Conclusion*

The Hyperloop is a technology that is still rapidly evolving—the second SpaceX competition in August 2017 will be the site for further developments that shape the future of its development, and much more work has yet to be done to prove the technical, and economic feasibility of the technology. However, the progress made by the Waterloop team is a significant first step towards the actualization of the technology into commercial use, and the testing done with the *Goose I* built prototype will contribute important data about the behavior of several key Hyperloop systems. Although Musk may consider the Hyperloop to be a wholly new “fifth mode” of transportation, the Hyperloop is actually the latest iteration in a long lineage of pneumatic tube transportation concepts dating as far back as 1799. Since then, the technology has evolved, over time increasing the ambition of pneumatic transportation and bringing the technology closer to realization. Although the most popular method of levitation is maglev, the air bearing levitation selected by Waterloop is also not without precedent. While uses of air bearings in transportation technology are rare, they can still be seen in use in the Dorfbahn Serfaus underground subway in Austria, as well as a handful of cancelled projects. The design of the *Goose I* half-scale prototype’s shell was an iterative process, building on the knowledge gained at each step, as well as new precedents adopted throughout the process as a result. The first, and simplest version took its inspiration from the efficiency and simplicity of construction of commercial aircraft fuselages, the second from Buckminster Fuller’s Biosphere. Ultimately, contemporary 3D-printing, laser-cutting, and CNC milling technologies allowed for an efficient hybrid option to be created inspired by geodetic airframes. Finally, the sci-fi inspired design of the Waterloop *Goose X* concept vehicle was an important communication tool that has influenced the trajectory of Hyperloop design and aided the financing process by visualizing the experience of a full-scale commercial Hyperloop. Finally, simple cues in the infrastructure design were considered in order to suggest an optimistic future of the holistic and appropriate introduction of Hyperloop tracks into city centres. The concepts, technology, and strategies used in the Waterloop prototype are not new; however, by expanding on the knowledge of these technologies and combining them into a new form with more ambitious goals, a new precedent can be set in transportation technology that is cheaper, faster, more sustainable, and more convenient than other modes of transportation.

*Note:* As a founding member of Waterloop, I served as the Architectural Design Team Lead, Shell Subsystem Design Team Lead, and Marketing Team Lead between September 2015 and February 2017. For full credits, the current team can be found on the team website located here: https://teamwaterloop.ca/team/

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