Airlock System Concepts for Hyperloop

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For Hyperloop

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Vacuum management is an unavoidable aspect of Hyperloop design due to the fundamental requirement of the high-speed pods traveling in evacuated tubes. Through the application of airlock systems, the boundary between pod, tube and station will be maintained and each environment kept at the desired pressure. This paper will assess and compare different airlock configurations with the aim of minimising operating costs and increasing pod and passenger flow rates, all whilst providing a seamless experience to users.

I. INTRODUCTION

Given that the environment a Hyperloop pod travels in is a near-vacuum, an airlock system is needed in order to allow passengers to safely board and disembark from the pod. This system has two main objectives to fulfil: one is the technical challenge of designing a safe and cost-effective system that will maintain both the pod and tube at the required pressure and allow the transition from pod to station, the other is ensuring that the logistics of passengers entering and exiting the pod in stations is as smooth and as simplistic as possible. It must have a high perceived factor of safety; it cannot take too long and make the whole process feel sluggish and it must have an air of familiarity for passengers. It is important to pay attention to the latter, as the final Hyperloop concept, implementation and how the public will interact with these systems ultimately plays a large role in the feasibility of the concept. A multitude of solutions can be considered using either chambers or docking systems.

II. AIRLOCK CHAMBER SOLUTIONS

An airlock chamber solution involves an end section of the tube in which the pod will travel in being replaced by an airlock chamber. This airlock chamber needs to be long enough to contain a pod and be as small as possible in diameter, so that a minimal volume of air needs to be vacuum pumped saving time and reducing costs.

A. Time and Cost associated with Vacuum Pumping

In order for an airlock chamber to transition between the pressure in the tube and the atmospheric pressure present in the station the area must be vacuum pumped. This use of pumps subsequently carries a cost, both in time and money. Specifics for these variables would require more data, for example, tube dimensions, specific pumps used and size of the Hyperloop pod. As the size of a pod is influenced by the relationship between the performance of specific pod concepts and the associated economics of the required number of passengers, it has been decided that relative comparisons of the following airlock configurations will be made instead of committing to a specific pod design.

The following model described in 'Performance Evaluation of Vacuum System: Pump-down Time' [1] from the International Journal of Scientific and Engineering Research states the relationship between system properties and pump-down time. Based on practical results of vacuum-pumping the relationship between chamber pressure and pump-down time is shown in Figure 1 below, and states that for a given system, pump-down time tend to increase exponentially as airlock chamber pressure decreases.

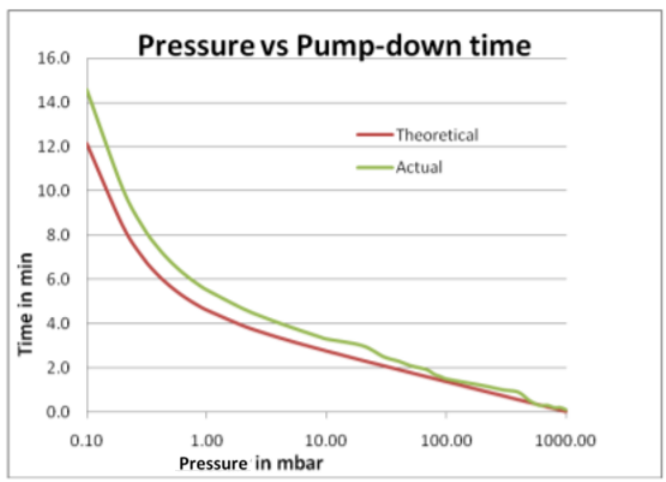

FIG. 1. Pressure Vs Pump Down Time [1]

The relationship between how pressure affects both pump-down times and motion of the pod through drag presents a further opportunity for optimisation. Furthermore, in order to analyse systems of varying configurations like the ones in this report, Knudsen Number and conductance must be considered [1]. For shorter pump-down times, conductance must be increased and in order to increase conductance, pipe diameter should be decreased, leading to the minimisation of airlock chamber size. Further research into simulating these systems more accurately and specific to a Hyperloop case can be carried out in the future and applied to the following concepts.

B. Twin Airlock System

The most simplistic concept would involve a pair of airlocks, one chamber at the end of the tube, at either end of the station. This will allow for both pressurization and depressurization, depending on if the pod was entering or leaving a station. Upon entering a station the pod would simply stop in the chamber, wait for the doors to close and the section to attain the same pressure as the station before the door ahead would open, allowing passage into the station. Upon entering the station through one of these airlock chambers, passengers can simply walkout, onto the platform, providing a perfectly familiar experience. New passengers can then board and the process would be repeated in the second airlock at the opposite end of the station where the airlock will now go from station to tube pressure.

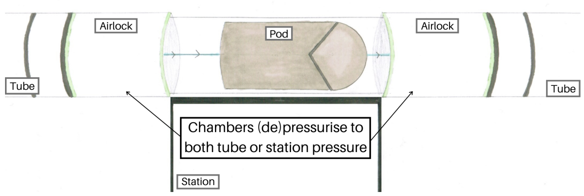

FIG. 2. Twin Airlock System

This method is undoubtedly the most simplistic to implement and provides the most familiar process for passengers. A combination of this familiarity and the relative simplicity of a vacuum chamber would most likely lead to a high perceived factor of safety. However, there are drawbacks to be addressed, the largest of which lies in the comparatively larger cost associated with the vacuum pumping of two airlocks, as opposed to the singular chamber proposed later. When assessing a single pod moving through a station this is not too notable; the first chamber needs to be pressurised from tube to station pressure with the pod in it and upon exiting the station the second chamber must be pumped from station to tube pressure, again with the pod in it. The problem arises when one begins to consider the next pod on the track entering the station; the first airlock now needs to be brought back to tube pressure without the pod in it, before it can be pumped to station pressure with the pod in it. Upon exiting the station, the same preparations will have to be made. The chamber must be brought up to station pressure without the pod in and then once the pod is in, pumped back down to tube pressure. This adds an additional cycle without the pod in to each airlock,

TABLE I. Summary of Twin Airlock System (Dis)Advantages

Advantages	Disadvantages
Will allow for fast embarkment and disembarkment, once the pod is through airlock chamber	Longest wait for pressurisation due to largest requirement of pumping area
High perceived factor of safety for passengers	Possible increase in station size and complexity due to larger number of required airlocks for higher pod frequencies
Comforting, familiar station layouts	Largest cost to pressurise due to larger requirement of pumping area
Can be easily implemented into stations, be it terminal or intermediate	

due to the area being greater without the pod in the airlock; this not only results in an additional cycle at the station, but each cycle requires a greater volume of air to be added or removed. This results in both a greater time and cost requirement when compared to the other concepts outlined in this report.

Not only will this large waiting time extend passengers journey but pods coming into a station will need to be less frequent to ensure queues of pods do not form. The only way to resolve this limitation on frequency of pods would be to construct more airlocks at a station. This will result in larger initial costs from both the additional airlock chambers and related tubing and also the larger station requirement to house these airlocks. Cost is not the only problem associated with increasing station size; it will also affect the distances passengers may have to walk through stations, which should be minimised to ensure the passenger experience is pleasant. Moreover, it is worth noting that due to the high speeds of Hyperloop it is widely thought of as an end-to-end method of transportation, with no intermediary stops between two stations. If this was the case, a track running all the way through a station with an airlock at each side is redundant as there is no need for the pod to stop at the station and continue onwards as every station would be terminal. Due to these evident drawbacks, it would prove useful to explore alternative solutions.

C. Single Airlock Chamber

Given the largest drawback to the twin airlock solution is the requirement of two airlocks, the use of a single airlock chamber should be considered. Similar to the twin airlock system, an airlock chamber sits at the end of the tube at the station boundary. However, with this concept only a singular airlock chamber is utilised and instead, on the tube side of the chamber, a split in the tube would be used leading different directions from the station.

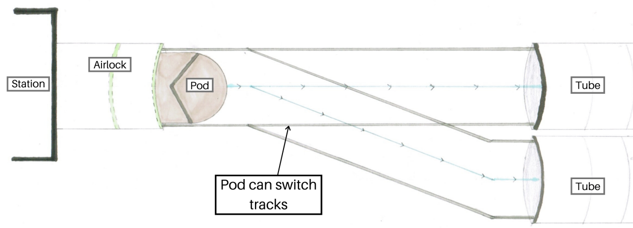

FIG. 3. Single Airlock System

This means the pod would need to be able to change which part of the track it is following. A system could be developed to safely allow this, either by a turntable system under the track or, more simplistically, something similar to a railroad switch. Evidence of this switch being feasible lies in its use in Virgin's Hyperloop concept [2]. With this fact in mind the single airlock solution seems to be of much greater benefit than the double airlock. In adopting this system, it will half the number of times the airlock needs to be pumped per cycle of the station, giving way to both reduction in wait times and costs of pumping. As a result of this it means frequencies of pods coming in and out of the station can be increased for a given number or airlocks, this offers a huge benefit to not only station design and layout but also the usefulness of the Hyperloop concept as a whole. Not only will journey times be shorter than high speed rail, but the departures can be much more frequent as well.

In addition to this, given the fact that Hyperloop will be suitable for direct-to-destination with no intermediate station, it allows for a reduction in the number of airlocks required. It is worth noting that if a compressor is utilised in pod designs, then the pod cannot simply reverse back into the airlock and continue its journey. It must first turn before entering the airlock, so that the compressor is at the front. However, this problem would only be unique to this airlock configuration if the service was not end-to-end and when inspecting an intermediate station. As with all the concepts discussed in this paper, a terminal station will always require a system to turn the pod, be it a literal turntable or simply extra track and station space for it to circle around [3].

D. Pod Doors

For any solution that utilises a large airlock chamber, allowing for the entire pod to leave the vacuum environment, a passenger flow perspective would demand doors that were as large as possible, just like the gull-wing doors shown in the Hyperloop Alpha concept [4]. Similarly, large sliding doors could also be used. This would allow for passengers to simply stand up and

TABLE II. Summary of Single Airlock System (Dis)Advantages

Advantages	Disadvantages
Will allow for fast embarkment and dis-embarkment once pod is through airlock chamber	Wait for pressurisation possibly limits frequency of pods still
High perceived factor of safety for passengers	There still remains a cost to pressurise, despite being lower than the aforementioned layout
Minimises costs and space in comparison to a twin airlock system	If an intermediate station was to be used there will be a slight increase in complexity due to the tube and track both needing to be split in different directions
Will still enable a comforting, familiar station layout for passengers	Additional track space or turntable will be required in order for pod to turn around if compressor is utilised

walkout to their side once in the station and unlikely result in congestion at the doors. However, once these concepts are considered in the vacuum environment of the tube, a problem arises in the huge pressures the pod operates under. Commercial airliners fly at an altitude no higher than 12 kilometres (km) generally [5]; at this altitude the air pressure will be around 2.73 pounds per square inch (PSI) [6]. For comparison, the pressure in a tube in the latest SpaceX Hyperloop competition is 0.12PSI [7]; therefore, more than a 20 times greater pressure difference that will be applied to a pod. A huge door like this combined with the very large internal pressures of the pod will result in very large structural loading of the door that may be difficult to design for, but not impossible. The challenge would be manufacturing something that is capable of withstanding these forces but also is sufficiently lightweight and compact.

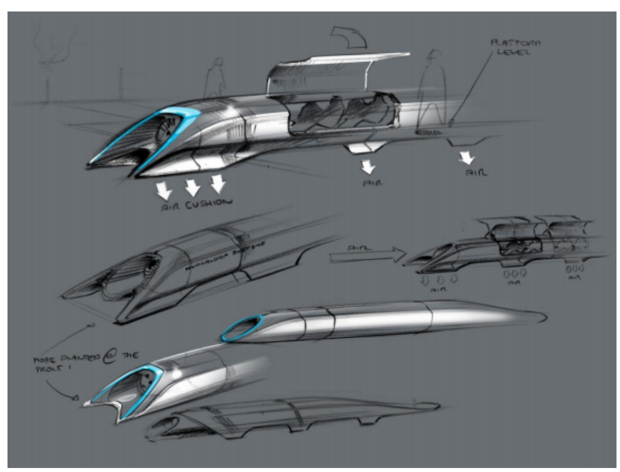

FIG. 4. Alpha Concept Sketch [4]

With current technologies, if side doors are to be considered for use on the Hyperloop pod it would prove useful to look at commercial aircraft doors as a starting point due to the similarity of the pressurised vessel, albeit much lower pressure differences in the case of an aircraft. This would mean using a plug door mechanism, once again having as many as structurally possible will be beneficial from a passenger flow perspective. Another alternative would be to look towards industrial applications of pressure vessels because the operating conditions result in an almost identical configuration between the Hyperloop pod and the tube it travels in. A widely used concept for vessels like this in industry is a tethered end door system, or an autoclave similar to the one shown below in Figure 5.

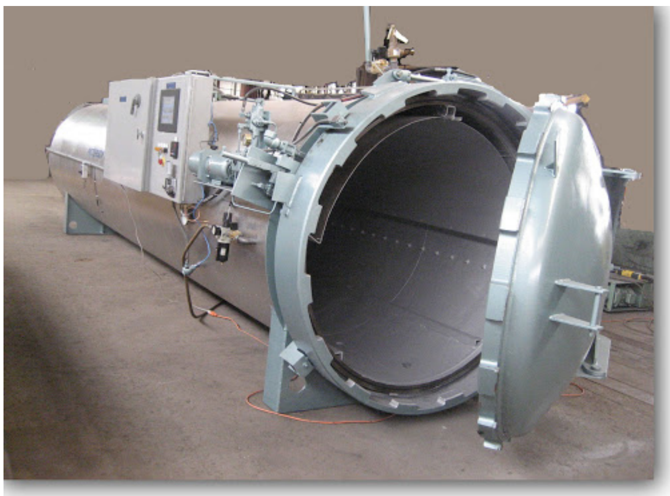

FIG. 5. Autoclave Door [8]

Using this method, the front of the pod will simply open up once it is out of the airlock in the station. This method of door works well as it is a proven existing technology for very high pressures. However due to the door being at the end it would seriously inhibit passenger flow in comparison to side doors. Therefore, if the pod is going to exit the tube completely through an airlock and enter the station, side plug doors make a much more attractive choice.

This End-Door system does prove useful when you consider a method where an airlock chamber is not used and the pod does not leave the tube.

III. END-DOOR AIRLOCK

The most sizable drawback to the previously detailed methods of vacuum management lies in the large area that requires vacuum pumping, increasing both time and costs of each station cycle. The only way to completely eliminate this factor is through the pod never leaving the evacuated tube and thus no area ever needing to be vacuum pumped. One method of doing this utilises the aforementioned end-door airlock. In this concept the pod will enter the station in the tube and, slowly approach the very end of the tube. As this process is underway, the front of the pod will be hinged upwards into a raised section at the end of the tube, allowing the now exposed, flat, front side of the pod to slowly dock with the end of the tube. Once securely affixed the front of the pod and tube can open into the station and allow for passengers to disembark through the end of the pod into the station.

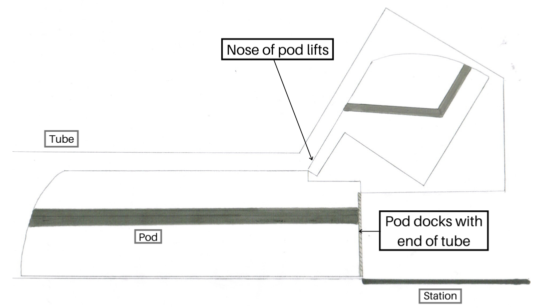

FIG. 6. End-Door Airlock

Along with the complete elimination of vacuum pumping requirements, this method will require no further infrastructure to be built, just a docking interface on the inside of the tube, potentially reducing the size and complexity of the stations. Subsequently this method undoubtedly boasts the lowest operational costs. However, further work will reveal if the speed at which the pod will need to travel at in order to dock, along with the time that the associated stability and guidance systems require to align the pod perfectly for docking, will result in shorter wait times for passengers. In addition to this, the problem still stands that all passengers will have to exit through the end of the pod, and this will inhibit the rate of passenger flow and subsequently constrain overall pod length.

This system may cause complications in terms of packaging and compressor operation in the full-scale concepts, if the design utilises one, which is likely [9]. Similarly, as the pod never leaves the tube, it is also very difficult to allow the pod to turn so that the compressor is at the front side of the pod; doing so would require a huge widening of the tube to allow this or by installing a compressor on both sides. In addition to this the fact that passengers never actually see the pod itself may lead to some uncertainty in terms of safety which could have a large impact on the adoption of this technology.

TABLE III. Summary of End-Door Airlock (Dis)Advantages

Advantages	Disadvantages
Completely eliminates pump-down time and cost	Time required for docking may not be faster than vacuum pumping
Utilises a rather familiar pressure vessel seal solution	Never seeing the pod may result in passenger uncertainty
Requires little extra infrastructure, resulting in more station space	Lack of airlock chamber and style of door may complicate emergency procedures
	Will require turns in the track prior to the station if route is not end-end

IV. AIRLOCK BRIDGES

Another possible way to reduce the area that needs vacuum pumping could be through the use of much smaller airlock chambers that would attach to the pod in a bridge-like manner once the tube enters the station. Once in the station, instead of the pod exiting the tube itself, it could simply stop in a specific location in the end of the tube and airliner bridge type airlock chambers could attach to the side doors of the pod from the side of the tube. Once securely attached they can pressurise to station pressure and allow passengers to exit through them.

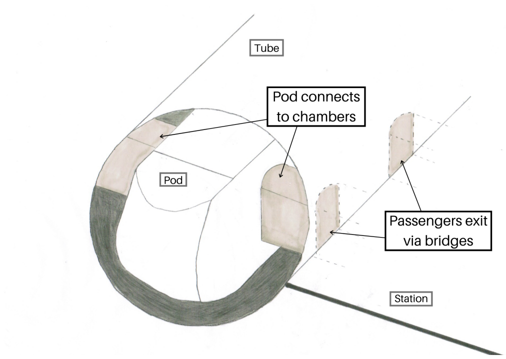

FIG. 7. Airlock Bridge System

This method invites further work into the relationship between passenger flow and thus the required number and size of airlock bridges in order to assess how much time and money it would save over a traditional airlock chamber solution. In addition to this, despite the familiarity of the airliner bridges, once again the passengers never actually see the pod, and this could result in lots of uncertainty around safety and willingness to adopt the service. Furthermore the positioning of the pod and airlock bridge system will most likely result in a rather complex system, and alone may take even longer than a vacuum pump pressurizing a whole chamber (this is before you consider that theses bridges then need to be pumped also).

TABLE IV. Summary of Airlock Bridge System (Dis)Advantages

Advantages	Disadvantages
No large airlock mechanism required	Rather complex mechanism, in docking pod to these bridges
Reduction in station size	Pod must be in very specific place within tube
Area requiring vacuum pumping may be reduced	Multiple mechanisms that could fail
	Multiple pressurisation systems required
	Never seeing the pod may result in passenger uncertainty

V. CONCLUSIONS

In the assessment of these individual solutions, we show how important the relationship between technical specifications and user experience is to the selection of a final solution. In addition to this, future areas of work essential to the evaluation of systems have been identified and will be carried out through further studies. With that being said, from the knowledge currently held, the Single Airlock system described, combined with plug-style pod doors, seems the most feasible and likely to be adopted by passengers due to its familiarity. The fact they can see the pod plays a large part in this as well, not only with regards to familiarity but also the ability to see this new, cutting edge technology and persuading people to adopt it through this. Next to this, the end-door airlock docking system holds promise but further study into the time and complexity of the procedure required to dock will need to be carried out to validate its feasibility. If it results in the system being more efficient in time and cost, the benefit of this will need to be compared to the impact of not seeing the pod on passengers' perceptions and the adoption of the concept.

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AUTHOR CONTRIBUTIONS

Bradley Craig as lead author wrote this paper and carried out the relevant research regarding airlock chambers, docking mechanisms and how the layouts of these systems in stations affect the overall Hyperloop concept. Jessie Huang produced the four graphics detailing each of the four concepts described.

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