ITSR Cover Page

EUROPEAN HYPERLOOP WEEK

This page is to be submitted with the ITSR by 13th December 2024.

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Awards Application

Full scale award : Technical aspects of hyperloop

Title of submission : ___*'Design study of a remotely operated repair pod for future Hyperloop systems'*____

General

General Introduction of Team

The Liverpool Hyperloop Team is a passionate mix of engineering and computer science students committed to advancing the future of sustainable, high-speed transportation within the UK. Our team is split into 4 sub-teams; Magnetic Levitation, Electronics & Software, Vacuum Tube and Chassis along with 2 presidents and a professor to advise and check through our research. The team stands for innovation, collaboration, and a relentless drive to solve complex challenges in the development of Hyperloop systems. We aim to increase the size and funding for our team in the coming years to hopefully be able to enter into the Demonstration category and in the long-term, as a team we strive to contribute to the transformative transportation technology of Hyperloop, changing transportation for the UK and the rest of the world.

List of Team Members

Name	Function
Harris Mohd Idzam	President
Daniel Cheng	Vice President
Professor Matt Murphy	Advisor
Lemar Tokham	Electronics & Software Team Lead
Emilio Vargas Flores	Chassis Team Lead 1
Tom Tait	Chassis Team Lead 2
Michelangelo Esposito	Magnetic Levitation Team Lead 1
Alexander Ashdown Brandstrom	Magnetic Levitation Team Lead 2
Monthon Chavan	Vacuum Tube Team Lead
Mateus Padilha Luz	Electronics & Software Member
David Spencer	Electronics & Software Member

Yingjun Xiang	Electronics & Software Member
Hakmed Olarinde	Chassis Member
Yadukrishnan Cherlan Poovalappil	Chassis Member
Shahmir Shahid	Chassis Member
Reagan Ramos	Chassis Member
Kubura Mohamed	Magnetic Levitation Member
Mansoor Badru Wamala	Magnetic Levitation Member
Sobaan Aamir	Magnetic Levitation Member
Mohammad Ahmed Khan	Vacuum Tube Member
Keyur Vara	Vacuum Tube Member
Kas Ahmed	Vacuum Tube Member

Motivation to Competition Awards

Motivate why you are applying for a research submission at the EHW and why it fits the award that you are going for.

As a team of students across Mechanical Engineering, Aerospace Engineering, Computer Science, Electrical Engineering and Electronics we are all passionate in applying what we have learned at university, from simulations and design to theory and calculations, to a technical research project.

Since this is our first year of applying to EHW, we aim to focus solely on our research concept and produce designs. Then in the coming years we can increase our knowledge of the myriads of concepts within a Hyperloop system to eventually create a full scale team to manufacture Hyperloop components.

The technical aspects of Hyperloop systems is a wide range of systems that we are keen to explore. Since this technology is an under-developed area of research, it gives Liverpool Hyperloop the opportunity to explore concepts for our '*Design study of a remotely operated repair pod for future Hyperloop systems'.* As a team, we all share this excitement to research into a concept that has never been done before, especially with one such as ours that is ambitious and challenging. Exploring this challenge and researching a niche topic such as Hyperloop systems are what motivates us to complete this report.

Furthermore, recognising Hyperloop as a sustainable method of transport is an interest that motivates us. We believe that as the world becomes more sustainable, Hyperloop is a key factor that could play a part in the future of transportation globally. Our dream is to develop a safe, fast and secure Hyperloop system that can connect major cities such as Liverpool and London.

Having the opportunity to take part in the competition at Groningen is a great reward. Competing in an international competition motivates us to gain recognition and opportunities, but also motivates us to understand the standard of research we produce, pushing us to strive for perfection.

Research

Title of Research

Design study of a remotely operated repair pod for future Hyperloop systems

Motivation of Subject

The high speeds of Hyperloop systems combined with the low pressure vacuum tube environment makes efficient maintenance and repair an aspect of utmost importance for any future system to ensure the safety of passengers and staff, as well as for the efficient operation of the system. Maintenance on conventional railway systems is manual; a fault is detected by a member of staff and reported to the head office, which dispatches a team to the site who then performs the repair. This process requires relatively large amounts of time and money, but works reasonably well in conventional railway systems where trains can simply be diverted onto another track. However, in Hyperloop systems there is often only one track and tube, as well as frequent departures at very high speeds, necessitating faster repair work to maintain efficiency. The vacuum environment also poses a problem in that the tube would need to be pressurised to allow staff to perform tasks. These considerations demand a novel approach to maintenance and repair of the system that is much faster and more responsive.

Modified railroad cars are commonly used for various maintenance and repair operations on conventional railway systems, such as to straighten or realign tracks. Taking inspiration from this, we are proposing a maintenance and repair system for future Hyperloop systems based on a system of sensors for detection of faults, software for control, and a specialized Hyperloop pod with the capability to perform fast and efficient repairs with significantly reduced labour effort. This pod would travel along the Hyperloop track using a combination of the same magnetic levitation and propulsion system as the regular passenger pods and a wheel system to the *location where the fault was detected, where it would perform repair and maintenance using robotic arms and equipment. These repairs could entail sealing a leak in the vacuum tube, realigning the track, or picking up debris. The system would rely heavily on software and robotics, only requiring a remote human operator to interact with the fault detection software, and then to operate the pod itself.*

Scope of Research

The remotely controlled pod is designed with safety and repair operations in mind. It is anticipated that, in many scenarios, the magnetic levitation rails may be non-functional or entirely inoperative. To address this, the pod will be equipped with deployable mechanical wheels, enabling it to travel to the intended destination. Consequently, the design will incorporate both a friction-based braking system and an electromagnetic braking system, the latter being used if the issue does not involve the magnetic levitation track. While the pod will achieve higher speeds when utilising the magnetic levitation track, the focus of this research is to ensure efficient and effective operation when relying on driven wheels. Therefore, a detailed analysis of the magnetic levitation system falls outside the scope of this phase of research, as the implementation of a magnetic levitation propulsion system is reserved for Phase 2 of the design process.

Furthermore, the pod must be capable of operating when the primary hyperloop power system is offline. This necessitates the inclusion of an auxiliary backup power system. The backup system must generate sufficient torque to enable safe yet swift travel, ensuring the pod can promptly reach its destination for critical repairs. Additionally, it must provide adequate force to tow a stranded hyperloop pod carrying passengers, assuming the hyperloop pod itself is equipped with deployable safety wheels. As the name implies, the Backup Power System must remain independent of the main hyperloop power sources. To meet this requirement, the pod will feature a remotely charged onboard battery powered by an external renewable energy source outside the vacuum tube.

The scope of this research focuses on understanding and addressing the challenges related to the pressure systems and HVAC (Heating, Ventilation, and Air Conditioning) systems within a Hyperloop pod. The primary aim is to identify potential failures, such as pressure fluctuations, leaks, and inefficiencies in air circulation, and to explore methods for detecting and monitoring these issues in real-time. This includes studying technologies like advanced pressure sensors, vacuum pumps, and redundant pressurization systems to ensure a safe and controlled environment within the pod. The research will emphasize conceptualizing solutions for effective air circulation, leak detection, and pressure stability while remaining scalable for future Hyperloop implementations.

This research will not delve into providing direct solutions or the engineering of final designs for these systems. Instead, the focus will remain on identifying potential problems, understanding their impact on the pod's operation, and investigating detection and monitoring strategies. Topics like thermal regulation, vacuum tube design, or passenger-specific systems will be excluded, as they fall outside the immediate scope of maintaining a maintenance pod's pressure and air quality. These exclusions are necessary to maintain a focused and actionable scope while aligning with the current project phase, which emphasizes operational understanding rather than full-scale system development.

By narrowing down the study to detection and conceptualization, the research provides a framework that basically addresses the critical aspects of pressure and HVAC systems in the Hyperloop pods. Insights from these will drive the subsequent development phases with practicality and focus on mind. The focused approach to the problem ensures that the research delivers results with value to the implementation of Hyperloop by setting safety, efficiency, and reliability standards without dissolving efforts in tangential topics.

Considering the complex design and the operating environment through which the pod travels, it is possible to identify two main areas regarding the chassis that need to be reviewed in detail to ensure appropriate safety conditions, Possible Structural Failures and Vacuum Integrity Issues. The presence of a failure within these areas during the operation of a Hyperloop vehicle could have catastrophic consequences.

It is important to mention that the scope of this research will not include solutions to the problems that can occur, in relation to the two main areas of focus, but rather being aware and detecting these issues that can arise. With a hope that in the future we can use the information gained from this research to actually begin to solve these problems, maybe by the use of semi autonomous robotics.

The structural failure considerations that will be researched with regard to the hyperloop chassis are, cracks, deformation, and material fatigue under the extreme conditions of a vacuum tube. Also the possibility of a real-time monitoring system to detect these failure types will be explored.

The materials for the chassis must be high strength and lightweight (e.g. carbon fibre). There will be an emphasis on researching materials that have high tensile strength, fatigue resistance, as well as compatibility with the magnetic levitation and vacuum tube systems.

As for the research into the geometry for the chassis, we will focus on optimisation for structural integrity. Highlighted by stress distribution to prevent localised failure and design adaptations to withstand vibrations.

The conditions of a hyperloop tube places significant stress on the walls of the chassis, which in consequence must be strong enough to withstand it without collapsing or deforming. Considering the aforementioned, a proper material selection and a detailed design process is crucial to minimize any kind of material weakness issue or design flaw that may compromise the pods integrity.

Another important aspect about the pods Vacuum Integrity is the seal. The primary function of the pod seal is to create an airtight barrier that ensures the interior of the hyperloop pod maintains a stable and controlled environment. This is crucial for both passenger safety and comfort as well as for a proper functioning of the pod's systems. A sudden seal failure could lead to an influx of air into the cabin, disrupting the low-pressure conditions of the tube and causing a sudden increase in drag and therefore a potential mechanical failure. At the same time, a sudden air infiltration could lead to rapid decompression of the pod, which would be dangerous to all the passengers inside.

The scope of the research regarding the Chassis component is to develop a proposal that includes the materials and geometries that could be feasible to manufacture the structure of the pod; which should guarantee the integrity of the vehicle taking into consideration the conditions to which it is subjected. In the same way, it is proposed to include the preventive measures to be taken to guarantee the vacuum integrity, where the viability of concepts such as ‘Multi-layered Seals’, ‘Vacuum Maintenance Monitor Systems’ and ‘Redundant Sealing Mechanisms’ will be explored.

The Electronics & Software research is focused on conceptualising a framework that enables a remotely operated maintenance pod to detect, assess, and respond to hyperloop infrastructure issues. Specifical, this includes:

In Scope:

- ***Sensor Selection & Placement:*** *identify sensor types (e.g ultrasonic for cracks, pressure sensors for leaks) and outline their conceptual arrangement to monitor structural and environmental conditions.*
- ***Data Processing & Communication:*** *Define how sensor data flows from embedded microcontrollers to a master control unit (e.g. Raspberry Pi), and then to a remote control interface, ensuring reliable data exchange.*
- ***Basic Decision-Making Logic:*** *Introduce threshold-based rules to convert raw sensor data into actionable alerts and recommendations*

- ***Remote Operation Fundamentals:*** *Establish how operators can remotely guide the pod, respond to anomalies, and initiate simple corrective actions (e.g., slowing the pod or triggering backup systems)*

Out of Scope:

These advanced implementations and integrations are excluded at this stage to maintain a manageable scope for initial research and to allow future phases to build upon a stable conceptual foundation:

- *Detailed hardware/software implementation (e.g PCB layouts, code development)*
- *Advanced autonomous repair algorithm or A-driven diagnostics*
- *Full integration with other subsystems at a tested, final stage*

This scope sets a conceptual baseline that informs future development, testing, and integration efforts.

Methodology

Literature review on suitable sensor technologies and communication protocols: *Examine established sensor technologies used in harsh or isolated environments. This informs the selection of sensors (e.g ultrasonic for cracks, pressure sensors for leaks) and communication standards (e.g CAN-BUS for reliable in-pod data exchange)*

Conceptual System Design: *Using insights from literature, we will draft high-level block diagrams showing how sensors connect to microcontrollers, how data is aggregated and processed by a master control unit (e.g Raspberry Pi), and how alerts reach a remote operator interface. Basic decision-making logic (e.g, threshold-based anomaly detection) will be outlined to illustrate how software transforms raw sensor readings into actionable information*

Feasibility & Trade-Off Analysis: *We assess the proposed architecture against criteria such as reliability, redundancy, and ease of future expansion. For instance, we consider what happens if a sensor fails or if we need additional sensors in the future. While prototypes are not yet built, this step ensures our conceptual design is flexible and robust enough to handle real-world challenges.*

Analytical Research and Literature Review: Involves a comprehensive review of existing literature, studies, and technical resources on pressurization systems, HVAC systems, and vacuum technologies used in related fields, such as aerospace, submarines, and industrial vacuum applications.

Simulation and Computational Modelling: Using simulation tools like Computational Fluid Dynamics (CFD) for air circulation analysis and Finite Element Analysis (FEA) for stress analysis under pressure differentials. This method will simulate various scenarios, such as leak events, pressure fluctuations, and air circulation patterns, to study their effects on the pod's internal environment. Simulation allows the exploration of potential failures and system behaviours in a controlled virtual environment. It eliminates the risks and costs associated with physical prototyping in the initial stages and ensures a thorough understanding of complex interactions between components.

Scenario Analysis: Use of scenario-based evaluations of the conceptual model to test its effectiveness against hypothetical challenges, such as seal failures, pressure fluctuations, or oxygen depletion. This will include defining operational thresholds and outlining system responses to potential failures. Scenario analysis provides insight into the system's capabilities and limitations under varying conditions. It supports the conceptual design by ensuring it addresses realistic operational challenges and safety concerns.

Overview of Research

Maglev:
Chapter 1: *Research into magnetic levitation and propulsion completed*
Chapter 2: *Next step will be to design a wheel propulsion system based on EHW infrastructure, including friction-based braking.*
Chapter 3: *After that, a backup power system will be designed in conjunction with E&S*
Chapter 4: *Finally, CAD and FEA software will be used to analyse the design*

Chassis:
Chapter 1: *Research into different feasible materials to manufacture the pod considering properties such as high strength and lightweight.*
Chapter 2: *Develop a proposal for a feasible material and manufacturing process to build the structure and aerodynamic shell of the pod.*
Chapter 3: *Geometry proposal for the main structure and the aerodynamic shell of the pod. Explore the viability of using Superellipses and Biomimetics to achieve better aerodynamic results.*
Chapter 4: *Research about possible structural failures such as cracks, deformations and material fatigue.*
Chapter 5: *Scenario analysis of possible vacuum integrity issues, and explore viability of adding 'Multi-layered Seals', 'Vacuum Maintenance Monitor Systems' and 'Redundant Sealing Mechanisms' to ensure safety.*

Vacuum Tube:

Chapter 1: *Research into pressurization and HVAC systems completed, focusing on identifying potential failures, leak detection, and system redundancies.*

Chapter 2: *Next step will be to develop a conceptual model of the pressure and HVAC system, including the layout of redundant tanks, ducting for air circulation, and integration of monitoring mechanisms.*

Chapter 3: *After that, scenario analysis will be conducted to evaluate the conceptual system under potential failure modes, such as seal breaches, pressure drops, and oxygen depletion.*

Chapter 4: *Finally, the conceptual design will be documented and presented using diagrams and flowcharts to illustrate system components and their interactions, providing a foundation for future Hyperloop development.*

Electronics & Software

Chapter 1: *Introduce the need for remotely operated maintenance pod, emphasising operational challenges within a vacuum-sealed, high-speed hyperloop environment.*

Chapter 2: *Identify structural and environmental issues the pod must detect, shaping the sensor requirements and data handling strategies for the Electronics & Software framework.*

Chapter 3: *Presents the conceptual E&S architecture. This includes sensor selection, data flow diagrams, and basic decision-making logic, all supporting remote operation and timely maintenance interventions.*

Chapter 4: *Outlines how this E&S framework could be integrated with other subsystems, such as chassis or maglev, in later development phases.*

Chapter 5: *Summarises the conceptual design, highlights areas for further refinement and validation, and recommends next steps for prototyping, testing, and eventual implementation.*

This overview shows how Electronics & Software fits into the broader research narrative, progressing from problem definition and requirements to a conceptual solution and future integration possibilities.