HYPERLOOP
GLOBAL

# Hyperloop Global

## 2025 RULEBOOK

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## 1. Important Deadlines for Hyperloop Global 2025

**Nov 1** White Paper Due

**Nov 4-15** 1st Jury Meeting

**Nov 30** Virtual Showcase

**Jan 6** Preliminary Design Review Due

**Jan 13-24** 2nd Jury meeting

**Feb 3** Research proposal Due

**March 29** Final Design Review Due

**April 1-13** 3rd and final jury meeting

**April 1** Early bird pricing ends

**April 21** Completed Research Paper Due

**May 12** Food sign-up closes

**May 30-June 1** Conference Weekend

**Submit all documents on the specified due date here. Please email info@hyperloopglobal.ca with any questions.**

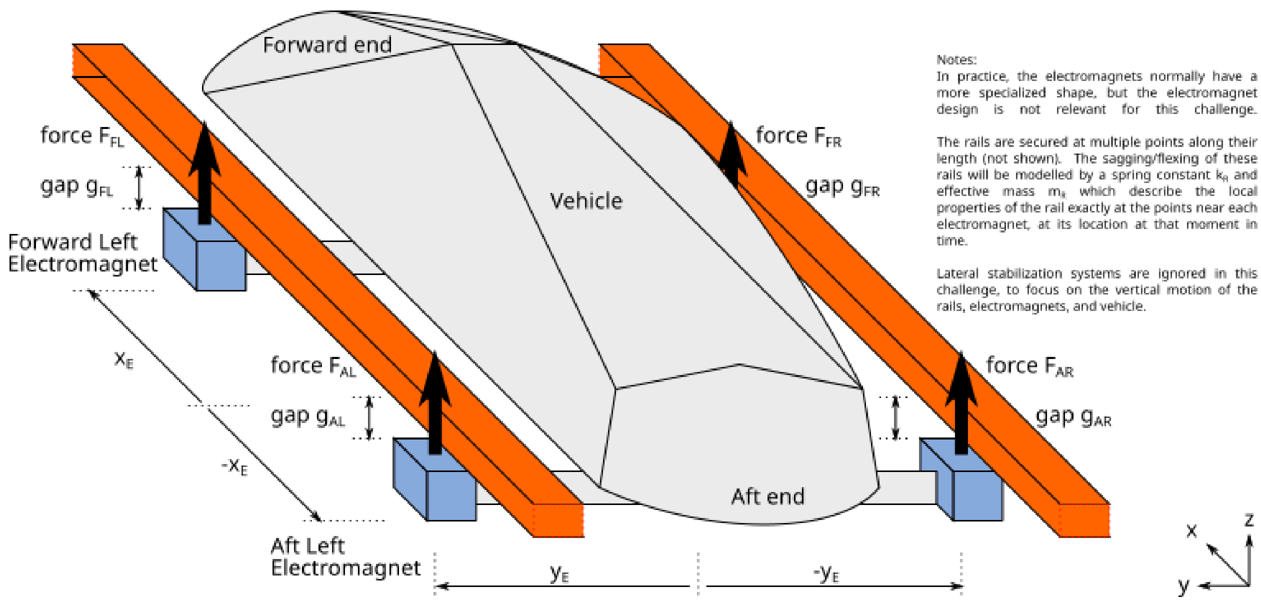
## 2. Transpod Challenges

This year the Hyperloop Global team is excited to present the Transpod Challenges! Please review all details and submission information below. Thank you to the TransPod team for putting together these challenges!

# Challenge 1: Magnetic Levitation Control

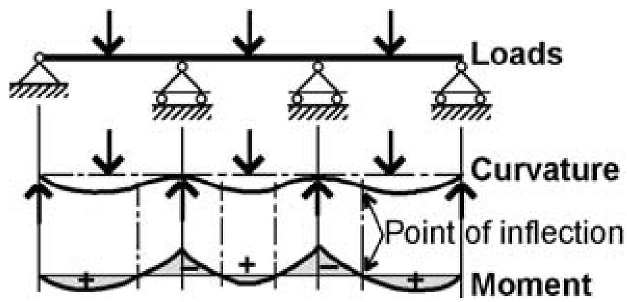
This challenge is for high-speed vehicles, including MagLev, FluxJet, Hyperloop, VacTrains, and other types of high-speed trains with magnetic levitation.

Imagine a vehicle which is traveling on a linear guideway, supported by 4 magnetically attractive systems attracting up to two rails. Magnetic attraction is unstable – the closer an electromagnet gets to a rail, even by a fraction of a millimeter, the higher the force of attraction, and this creates positive feedback which would go out of control and crash the electromagnet into the rail! Therefore, you need to design a control system to automatically adjust the electromagnet's force to keep the magnetic gap distance constant. (The gap is the distance between an electromagnet's surface and the rail.) In real life this gap is usually kept at around 5mm to 10mm. Since the rails and electromagnets can all vibrate due to their attraction forces, you will have an interesting challenge!




Your challenge is to design a control system to control the 4 forces, $F_{FL}(t)$, $F_{FR}(t)$, $F_{AL}(t)$, $F_{AR}(t)$. Your only information is 4 sensor readings measuring the vertical gap in millimeters at each electromagnet, $g_{FL}(t)$, $g_{FR}(t)$, $g_{AL}(t)$, $g_{AR}(t)$. For the basic version of this challenge, we will ignore the side-to-side stability of the vehicle and only consider 4 vertical controllable electromagnets that stabilize the vehicle using their vertical motion. We will also consider the vertical vibration of the rail, and the vehicle's vertical motion, plus the vehicle's pitch & roll rotation (which is very small, but still causes the electromagnets to move up and down when the vehicle pitches or rolls slightly).

A guideway or rail will sag/flex due to its own weight plus the levitation forces pulling it down, which is an extra reason for this control system. The control system needs to constantly conform to the guideway as the vehicle drives forward; otherwise the gap distance will alternate between too small and too big.



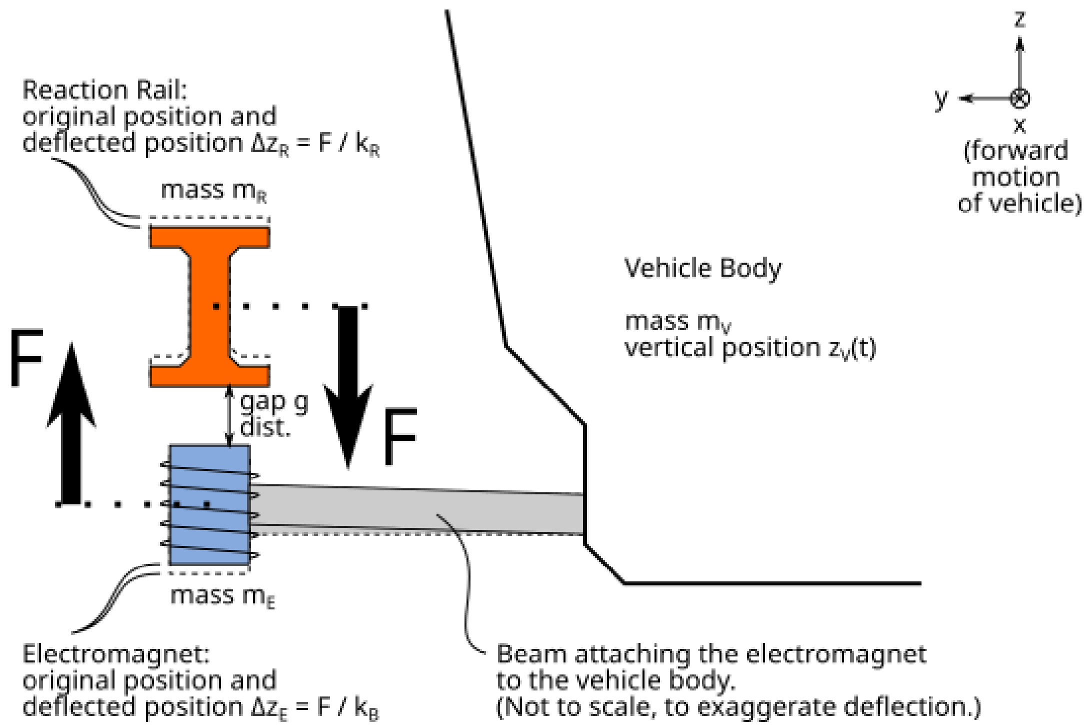

Vehicle travel direction ——->
on this guideway

Your challenge is to design a control algorithm (or mathematical model) to stabilize your levitation systems in order to levitate the vehicle.

This challenge is interesting because:

- The electromagnets need to be controlled very quickly (with rapid control signals – because the magnetic attraction is unstable and fast-acting).
- The rails flex up/down in response to the attraction, making the system more unstable.
- The vehicle beams flex up/down in response to the attraction, making the system more unstable.
- If the rails are slightly uneven (by construction, even by 1mm) so the 4 gaps cannot be equal, your system needs to make a compromise.
- When one electromagnet moves closer to the rail, you need to control more than just that one electromagnet. Since the vehicle makes a very tiny rotation, it also has an effect on the other electromagnet gaps! So you are really doing multiple-input multiple output control of all 4 electromagnets.

So your challenge is to draw a diagram, and write equations, to show how the sensor signals (measuring gap distance g) can be transformed into control signals to control the electromagnets' force (F).




Your control system model can be imagined to be running on a computer on the vehicle. You are receiving sensor readings (below), and you need to use them to decide on your control outputs to control the electromagnets. Here are the inputs to your control system model: (time-varying signals)

- $g_{FL}$ - gap distance sensor (mm) for the forward left electromagnet. The sensor measures the distance between the surface of the electromagnet and the rail that it's attracting to.
- $g_{FR}$ - gap distance sensor (mm) for the forward right electromagnet
- $g_{AL}$ - gap distance sensor (mm) for the aft left electromagnet
- $g_{AR}$ - gap distance sensor (mm) for the aft right electromagnet

These are the outputs of your control system: (time-varying signals)

- $F_{FL}$ - force of attraction generated by the forward left electromagnet
- $F_{FR}$ - force of attraction generated by the forward right electromagnet
- $F_{AL}$ - force of attraction generated by the aft left electromagnet
- $F_{AR}$ - force of attraction generated by the aft right electromagnet

Your system should be written out as a signal flowpath diagram (signals can be combined by adding, subtracting, multiplying, dividing, and other functions, e.g. matrix algebra, lookup tables, time-integral, time-derivative, etc), and/or as equations. Create your model as a diagram and/or equations and then code, imagining that it reads in the above sensor readings on a computer, and controls the outputs.

Below are physical parameters of the mechanical system. You can write out simple equations ($F=k*\Delta z$, $F=m*d^2z/dt^2$) for the 8 mass-spring systems, and the vehicle motion (only up/down, pitch, roll). You can then write these equations/variables as code (in Matlab or Octave or Simulink or other language) to simulate (the mechanical system's response to your control system! They are deliberately left as variables (not fixed numbers), so that you can make your simulation model use these variables inside it.

| Parameter | Meaning | Comment on how it's modelled |
|---|---|---|
| $m_R$ | mass (effective) of the rail affected by <u>one</u> of the electromagnets | **Rail vibration**: (up/down)<br>Please use 4 mass-spring systems to model the rail's vibration, locally near each of the 4 electromagnets. The mass-spring models are a good approximation of an "effective" mass and spring constant of rail at 4 local sections. The springs represent vertical motion only. One end of each spring would be attached to the mass $m_R$ (which also experiences the attraction force $F$), and the other end of each spring should be stationary. |
| $k_R$ | spring constant (effective) of the rail representing its vertical motion as it tries to return to its original straight shape | |
| $m_E$ | mass of one electromagnet system | **Electromagnet vibration:** (up/down)<br>The electromagnet and its beam are modelled as a mass-spring system. Please make 4 up/down mass-spring models (vertical only). One end of each spring would have mass $m_E$ (which also experiences the attraction force $F$), and the other end of each spring is coupled to the vehicle frame, so that when the vehicle moves up/down or pitches or rolls, the other end of each of the 4 vertical spring models experiences a vertical motion corresponding to its location ($x_E$,$y_E$) around the vehicle. |
| $k_B$ | spring constant of the suspension beam holding the electromagnet system. (Even though it would be very strong, it still has some flex given the large forces involved.) | |
| $m_V$ | vehicle mass (total) | **Vehicle motion:** (up/down, pitch, roll)<br>Forces from gravity and 4 electromagnets. Vertical motion can be modelled with $F=ma$. And $\tau=I\alpha$ for pitch and roll. |
| $I_{V,y}$ , $I_{V,x}$ | moment of inertia of the vehicle (pitch and roll) | |
| $x_E$, $y_E$ | x and y offset positions of the electromagnets away from the vehicle's centre of mass. | You only need to consider these for (i) the torque exerted on the vehicle by each electromagnet, and (ii) the vertical position change of each electromagnet when the vehicle pitches or rolls. |

In your code or example model, you can use the following default values. But please make sure to **leave these parameters as variables** in your simulation model so they can be changed easily for different tests by the judges. Example numbers to use: $m_R$ = 15 kg, $k_R$ = 500 000 N/m, $m_E$ = 50 kg, $k_B$ = 1 500 000 N/m, $m_V$ = 1200 kg, $I_{V,y}$ = 1000 kg*m$^2$, $I_{V,x}$ = 250 kg*m$^2$, $x_E$ = 1.0m, $y_E$ = 0.5m

Timeline for the competition:

- December 1, 2024 - Virtual Showcase. Teams wishing to compete in this challenge will do a 15 min. slide deck presentation to judges from TransPod during the second day of the Virtual Showcase on Dec 1. In advance, teams should fill out the Virtual Showcase sign-up form. Teams do not need to submit their slide deck beforehand.
- After presentations are complete, the judges from TransPod will choose which teams will move forward to the final round. Participating teams will receive an email 1 week after the Virtual Showcase informing them if they are moving forward or not.
- May 12, 2025 - Final submission due (below) for the judges to evaluate and test before the competition event.
- May 30-June 1, 2025 - Competition event. Teams will give presentations showcasing their projects. Judges will ask questions. At the end of the event, the judges will deliberate and present an award to the top team(s).

Requirements of your final submission: (if you are accepted to compete after the Virtual Showcase)

- Your control system - presented both as equations and as a signal flow path diagram (PDF/doc.)
- Your mechanical system model - presented as simple diagrams of your mass-spring models, and equations of motion.
- Model file - of your **control system** & **mechanical system** models. The file can be Matlab/Octave code, or other programming language, or Simulink. The "mechanical system" part of the model should include your mass-spring models (with 9 parameter variables that the judges can change to any numbers during testing) so that you can simulate the vehicle dynamics coupled to your control system. The "control system" part of the model should have the required 4 inputs and 4 outputs linked to the mechanical part of the model. The judges will test it. Please only use vanilla versions of Matlab/Octave, Simulink, or other languages, and DO NOT use any special functions which require special tool boxes or features to be purchased for the software, because the judges will not be able to test your code.
- Written explanation, using equations or simulation, to show your reasoning for why you chose that control system model, based on the variables shown above. Explain your method for how you determined/tuned/calibrated your system's internal coefficients.
- Justify (using mathematics, and/or simulation, and/or real-world tests) that your control system is stable and controllable.

These must be submitted in advance (before the final competition weekend; see above) so the judges can test, check, and verify your results, to judge for the top challenge prize.

Bonus:

- For teams who want to build something while focusing on this challenge, you can have some team members build a physical testbench to test your control system!

- For teams who want to build a full vehicle, you are welcome to incorporate this levitation into your vehicle and demonstrate it at the competition!
- Robust control: Make your control system still work well when some of the 9 parameter variables can be varied instead of the default numbers (numbers below the table above). However, it still needs to work extremely well for the default numbers. (Otherwise, you can tailor your control system for the default numbers.)

# Challenge 2: Landing Gear Wheels

Centrifugal forces will be pushed to the limits at up to 1000 km/h, in this project involving advanced wheel design.

**High-Speed Emergency Landing Wheels** are useful for MagLev, FluxJet, Hyperloop, and other vacuum or high-speed vehicles that use magnetic levitation. When power is suddenly lost for any reason, these wheels can provide a safe emergency landing when the vehicle drops only a small distance.

Your challenge is to come up with a creative design for emergency landing wheels. The objectives will be to maintain high traction, without the wheel disintegrating at high speed, to allow emergency landings and braking.

You can use multiple materials if you want, such as a material on the outer wheel surface, a next layer, an inner wheel material, and even wires or strips of metal that are woven around inside, similar to a Mars rover or a lunar rover! You will just need to have a good reason for your design. There are many options.

Requirements of your design:

- Withstand centrifugal forces at up to 1000 km/h linear speed. Does not disintegrate. You will need to think about (and calculate) the optimum radius of the wheel, which affects this. Please show your calculations and optimization criteria.
- Capable of operating in a vacuum environment, down to a pressure of 100 Pa (1/1000 of an atmosphere). All materials must be vacuum-compliant with limited outgassing (see NASA's vacuum materials database). If you are using solids, metals, wire meshes, rubbers, this should be considered. If you decide to use gas-inflated tires (this is not necessarily recommended but is only one option), you should also be aware that the tire pressure differential will increase by 1 atm when the vehicle is inside a vacuum environment, and decrease by 1 atm when driving at normal air pressure, but must work well in both cases (both vacuum and also at atmospheric pressure). The guideway environment should be able to change its air pressure ranging from atmospheric pressure to low pressure, reaching as low as 100 Pa.

- Carry the weight of the vehicle. For simplicity, you can assume each wheel carries a weight force of 50000 N (~5000 kg), so with 4 wheels per vehicle, it supports a 20 tonne vehicle.
- Withstand a sudden contact with the driving surface after the vehicle falls down. The wheel must be able to withstand a momentary weight force of 500% during the landing compared to normal constant gravity, and also suddenly accelerate its rotation from zero up to full-speed rotation, caused by the high speed contact. Dynamic friction can optionally be much lower than static friction.
- High static friction against the driving surface to allow braking to be as strong as possible when brakes are engaged. Your goal is at least 20000 N of braking deceleration through the wheel, given the normal 100% gravitational weight (normal force) on it, to allow the vehicle to decelerate in an emergency without slipping. For guideway material, you can assume a driving surface of steel S355 (equivalent to ASTM A572Gr50). However, if needed, you can choose a coating material that can be applied to this steel in advance, adheres without degrading for 1 year, and meets all the other requirements in this list.
- Capable of handling irregularities/bumps in the guideway, with a focus on good shock absorption to ensure passenger comfort, for 1mm bumps. Must withstand 10mm bumps at an extreme.
- Withstand landings on a curved guideway surface (such as inside a tube) even if the vehicle dropped from a slightly offset lateral position or roll angle than expected. Assume the vehicle always has zero yaw angle (is pointing correctly in the direction of motion).
- Minimize damage and wear-and-tear to the driving surface on the guideway.

Propose a wheel design for a 1000km/h emergency landing. You are free to choose:

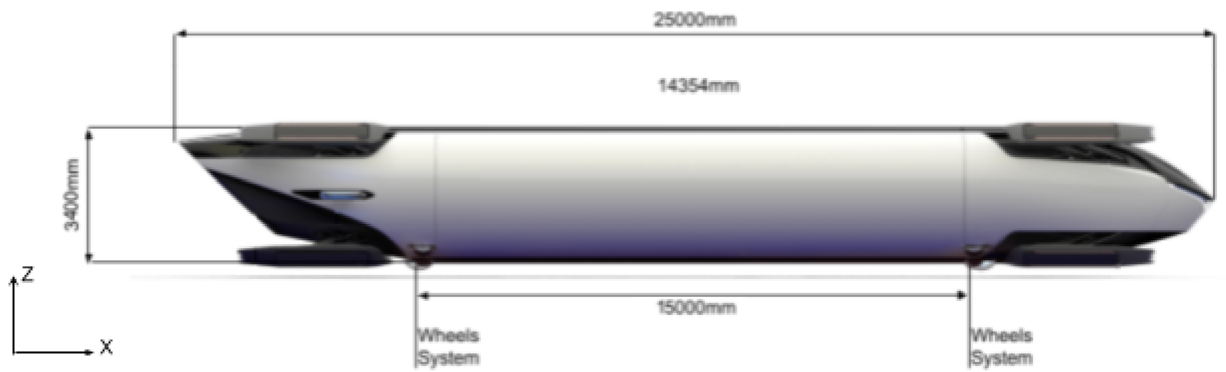
- Materials in wheel
- 3D mechanical design including any substructures, (e.g. optional core, layers, reinforcements, treads, integrations.)
- Wheel diameter (optimized)
- Wheel mounting angle (optimized)
- Wheel width and cross-sectional shape for a curved guideway surface
- Optional coating material(s) on driving surface

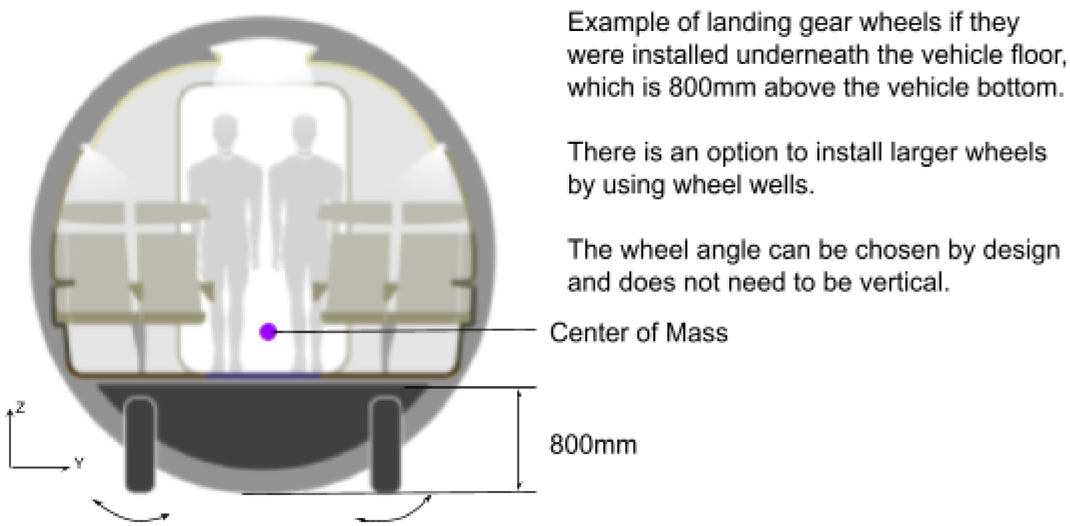
Assumptions to make your work easier::

- Shock absorbers/suspension systems can be assumed, but are not a core part of this challenge.
- During landing, don't worry about the position/collisions of any robotic levitation and propulsion systems, that's not the point of this challenge so just ignore them.

Example vehicle:

A vehicle measuring 25 meters in length, with an external diameter of 3.4 meters. Its landing gear spans 15 meters along the longitudinal axis. It is equipped with four landing gear systems, two positioned at the front and two at the rear. The vehicle's center of mass is centered, except vertically about 33% high from the bottom.  This vehicle is designed to operate in a guideway tube with a 4.0 m internal diameter.




Timeline for the competition:

- December 1, 2024 - Virtual Showcase. Teams wishing to compete in this challenge will do a 15 min. slide deck presentation to judges from TransPod during the second day of the Virtual Showcase on Dec 1. In advance, teams should fill out the Virtual Showcase sign-up form. Teams do not need to submit their slide deck beforehand.
- After presentations are complete, the judges from TransPod will choose which teams will move forward to the final round. Participating teams will receive an email 1 week after the Virtual Showcase informing them if they are moving forward or not.
- May 20, 2025 -  Final submission due (below) for the judges to evaluate before the competition event.
- May 30-June 1, 2025  -  Competition event.  Teams will give presentations showcasing their projects.  Judges will ask questions.  At the end of the event, the judges will deliberate and present an award to the top team(s).

Requirements of your submission:

- Diagram of one wheel, labeling its different parts, materials, components.
- Written explanation of your design, explaining how it satisfies each of the requirements above, by explaining the advantages/tradeoffs in the materials and construction. Reference your sources of information (on material properties, etc.)
- Calculations to show your optimization of wheel radius, and wheel mounting angle.
- Calculations or simulations to determine the braking force (static friction) at maximum speed and constant 100% gravity force.
- Simulations of the wheels' dynamics under the most extreme conditions. Verify structural integrity.

These must be submitted in advance (before the final competition weekend; see above) so the judges can test, check, and verify your results, to judge for the top challenge prize.

## 3. Hyperloop Global Conference

Hyperloop Global is an organization that brings together student hyperloop design teams, hyperloop companies and associated industry professionals under one roof. The annual conference provides student teams an opportunity to present and receive feedback on their pod designs and other hyperloop related projects in front of technical and business professionals from around the world. The event awards competing teams when excellence is displayed. If your team intends to attend the conference please fill out this form. Attendees will have the opportunity to attend workshops and keynote sessions, present their latest research papers, and test their pods on the test track.

### 3.1 Document Submissions

Teams will be required to submit 3 separate documents with information about their pod and its related components. The documents are made to build upon one another. Teams will also be offered the chance to meet with our jury members and receive feedback on their submissions on a first come first serve basis. The last document (Final Design Review) will be taken into consideration by jury members when judging your pod design for awards.

Here is the information that should be included in each document. Please see a short description of what should be included in each document below.

- White paper
    - Information on the design process of each subsystem.

- Preliminary Design Review (PDR)
    - The same information about the design process as the White Paper.
    - Include preliminary information about the manufacturing process, preliminary timeline, and budget.

- Final Design Review (FDR)
    - The same information about the design process as the PDR
    - The same information about the manufacturing process, timeline, and budget as the PDR
    - Information about the analysis and testing process of each subsystem

Teams will be given the opportunity to present their FDR to the jury at the conference.

**Note on deadlines:** The Hyperloop Global team will send out emails and post on social media to remind teams of the deadline for all document submissions. If a team submits any of their documents more than a week after the specified deadline, they forfeit their right to a feedback meeting with their assigned jury member for that specific document. In regards to the Final Design Review, for every day, up to 10 days, after the deadline that you do not submit, one point will be taken off for each award you are considered for by the jury members at the conference. **If you submit the Final Design Review more than 10 days after the deadline, you are still welcome to present at the conference and receive feedback but you will not be eligible to win awards.**

### 3.1.1 Document Submission #1: White Paper

The White Paper is a document that will outline the design process of the subsystems on your pod. The intent of this submission is for teams to provide documentation of their design process so jury members are able to understand and give feedback. Teams will submit their White Paper to Hyperloop Global jury members for technical review and feedback by **Nov 1 @ 11:59pmEST** to this submission form. Teams will meet with their assigned jury members to discuss feedback from Nov 4-15. More information about jury meetings will be released at a later date. We will match teams with jury members on Nov 1 after White Papers have been submitted.

The White Paper (as well as the other documents) will consist of a section dedicated to the design process of each subsystem. Each subsystem section will have a maximum page limit of 5, not including figures and diagrams. All figures and diagrams can be included at the end of your document in the appendix. There is no page limit for this section. All subsystems required are as follows:

- Structures/Chassis
- Braking
- Aeroshell
- Pressurized Systems
- Cooling Systems
- Guidance
- Electronics, Controls, and Communication
- Propulsion
- Levitation
- Power Systems
- Thermal Management Systems
- Other (Auxiliary or Experimental)

Each section dedicated to each subsystem should answer the following questions?

- Please give an overview of your design.
- What are the specifications of your design?
- What was the timeline of your design process?
- How did your team come up with the design? What research did you do?
- What challenges did your team face in the design process?
- How are you designing the next iteration of your subsystem differently?

### 3.1.2 Document Submission #2: Preliminary Design Review (PDR)

The Preliminary Design Review is a document that adds onto the work done in the White Paper by adding the manufacturing process of the subsystems of your pod, and preliminary information about timeline and budget. The intent of this submission is for teams to provide documentation of their manufacturing process so jury members are able to understand and give feedback. This document will be submitted by the team on **Jan 6 @ 11:59pmEST** to this submission form. Jury members will meet with teams to discuss feedback from January 13-24.

### 3.1.3 Document Submission #3: Final Design Review (FDR)

The Final Design Review is a document that adds onto the work done in the White Paper and the Preliminary Design Review by adding the testing/analysis process of the subsystems on your pod and safety assurance characteristics. The intent of this submission is for teams to provide documentation of their analysis and testing process so jury members are able to understand and give feedback. If your team intends to test on the Waterloop test track, the analysis/testing portion of the FDR will need to be approved before you are allowed to test. This Final Design Review is due on **March 29 @ 11:59pmEST** to this submission form. Jury members will meet with assigned teams from April 1-13 to discuss feedback.

### 3.1.4 Live Presentation of the Final Design Review

This year it will be mandatory for teams to give a formal presentation of their final design review to jury members. The presentation allows teams to present a custom-made slide deck for 15 minutes and participate in a Q&A period with jury members for 5 minutes. Teams will provide an overview of their pod's key features within the 15 minutes provided to them. The presentations will be used as part of the judging process. The Q&A answers will be evaluated as well.

Teams are not required to submit their presentations before their allocated time, but inappropriate or inaccurate information may result in negative consequences such as disqualification from some or all awards.

## 3.2 Research Challenge

Teams can submit one proposal for technical research and one for non-technical research. Upon submitting a completed research paper by the specified date, teams will be able to present their research at the conference for evaluation by jury members. Presentations will be live during the conference, for a maximum of 15 minutes with a 5 minute Q&A to follow.

Teams must submit a preliminary research proposal by **February 3rd** to this submission form to qualify to receive feedback from the jury members. Completed research papers are due on **April 21st** and can be submitted to the same form. Once a completed research paper is submitted, a team is eligible to present at the conference for award consideration.

### 3.2.1 Technical Research

Technical research is the R&D of a topic related to the Hyperloop pod, infrastructure, or relevant technologies. These submissions must be technical, meaning they must dive into the engineering, design, and/or sciences behind the experiments and designs. A technical paper ideally would include demonstratable prototypes or experiment results that can act as (at a minimum) the proof-of-concept or preliminary results. The papers in this category are meant to discuss the importance and implications of various approaches and experiments for topics related to Hyperloop. These proposals should provide more confidence, or give caution, to potential advancements in the hyperloop student community around the world. A technical topic could be about, but not limited to, any of the following:

- Artificial Intelligence usage in heat management systems
- Thermoelectric cooling systems for onboard components

- Studies on levitation and propulsion systems using compressed air
- Tunneling methods for underground Hyperloop tubes

### 3.2.2 Non-Technical Research

Non-technical research is about the business, environmental, economic, and social aspects of Hyperloop. Modern Hyperloop projects have shown that they require a high degree of understanding in topics such as how investors fund projects, the health concerns of passengers, and the choice between cargo and human transportation. These submissions should dive into a topic unrelated to the technical design or engineering aspects of Hyperloop pods, infrastructure, or other hyperloop technologies. Instead, this submission aims to enable the education of non-technical topics for the general public and other stakeholders, as well as student teams. A non-technical topic could be about, but not limited to, any of the following:

- Analysis of a potential Hyperloop track between Montreal and Toronto
- Marketing effectiveness of existing Hyperloop materials
- Increasing support and funding of existing Hyperloop projects
- Cargo transportation vs human transportation using Hyperloop

### 3.2.3 Proposal Structure & Format

To qualify to submit a completed research paper and present it at the conference, you must first submit a research proposal by **February 3rd** to this submission form. This submission should have a maximum of 5 pages not including tables, images, and citations. After a successful submission, you will receive feedback from our jury members. Your research submissions should include the following sections:

- Abstract (400 words maximum or 1 page)
- Introduction:
    - List of members and contributors, including supervisors if applicable
    - Background Information, description of research topic and objectives to meet
    - Specifications of this paper, including any research awards from academic organizations, and the award this paper is registered for (optional)
- Methodology & Tools/Equipment (if technical)
- Results/Analysis
    - Research findings
    - Discussion of results
- Bibliography

- Cite all sources that are relevant, use proper formatting

Completed research papers must include an abstract, tables, images, and citations whenever necessary. Follow scientific research format if technical (required), and business report format if non-technical (allowed). Maximum length of 20,000 words (excluding citations and appendices). Easy to read and formatted correctly.

#### 3.2.4 Research Presentation Format

The presentation is to be judged by industry partners (preferred) and/or Hyperloop Global jury to provide feedback and give awards for the best research proposal and the best presentation.

Each presentation will be 15 minutes long and is followed by a 5 minute Q&A session. The Q&A session is used as a way for teams to explain and defend their findings in front of jury members. Both the presentation itself and the Q&A session will be evaluated.

The winning research proposals will be posted on Hyperloop Global's official website, which can be removed or modified based on team requests and preferences.

### 3.3 Awards

The awards for the in-person competition are divided into 3 categories: technical awards, research Awards, and non-technical awards. Rubrics for awards will be released at a later date.

#### 3.3.1 Technical Awards

- Structure & Aeroshell Award
- Guidance System Award
- Braking System Award
- Electronics Award
- Power & Propulsion Systems Award
- Levitation System Award
- Complete Pod Award

#### 3.3.2 Research Awards

- Best Technical Research Award
- Best Non-Technical Research Award
- Best Presentation Award (Applies to both technical and research presentations)

### 3.3.3 Non-Technical Awards

- Spirit Award: Awarded to the team who shows the most team spirit throughout the conference.
- Impact Award: Awarded to the Business team (Marketing, Sponsorship, Logistics, and Finance) who has been able to create the biggest impact for their team. For example: a successful marketing campaign, being able to reach a sponsorship goal, managing finances well, etc.…)

## 3.4 Test Track Specifications

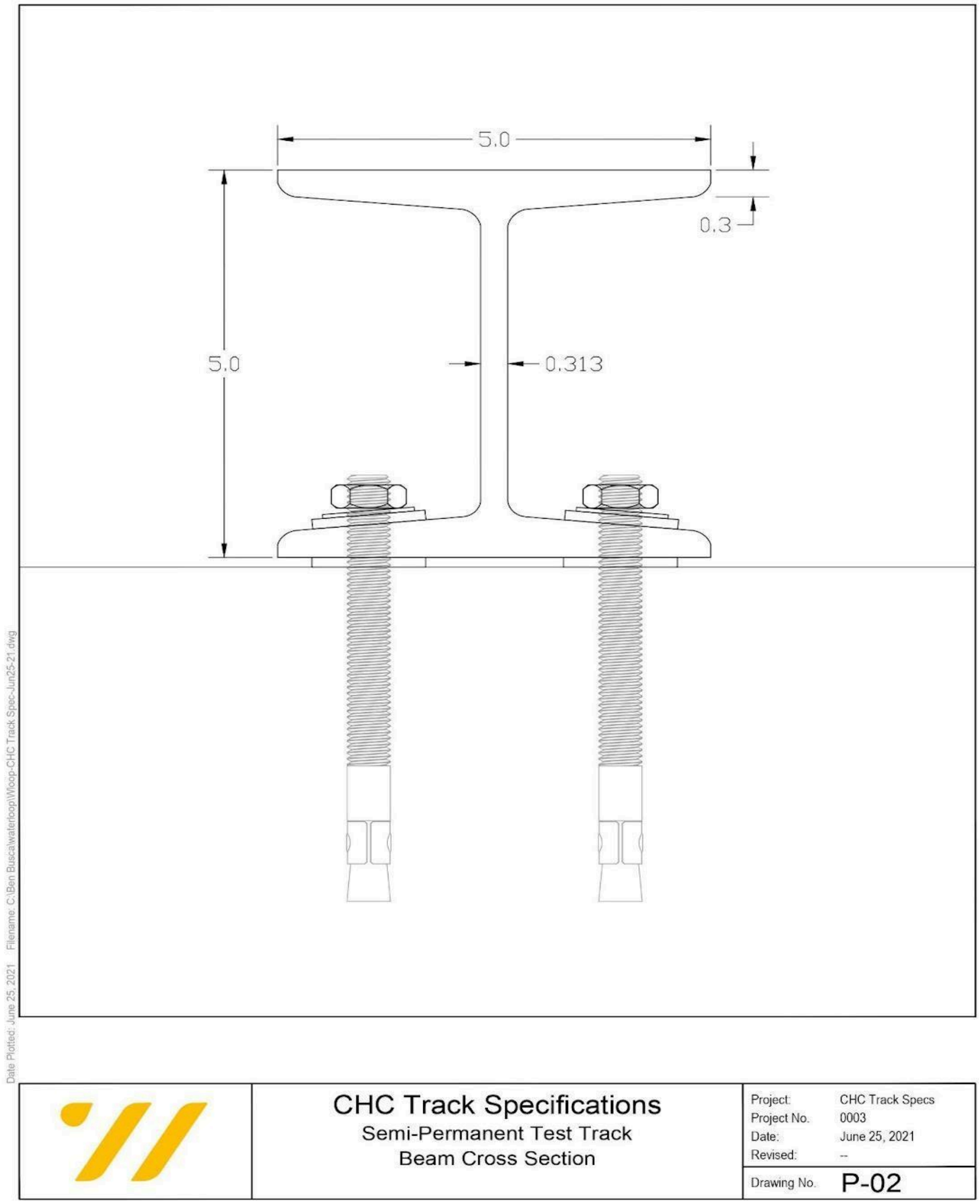
Hyperloop Global will be using the Waterloop Semi-Permanent Test Track. This is an I-beam track composed of 6061 T6-Aluminum mounted onto an intermittent series of concrete bases. The track is located at the Region of Waterloo International Airport. The length of the track is 100 m.

If a team would like to bring their own track to the competition (even if not I-beam track) they are welcome to do so.

### 3.4.1 Overview

Dimensions (in inches) are visible in Figure 1 and Figure 2 with a standard tolerance of ± 10% for the thickness of aluminum on an aluminum extrusion. And ± 5 mm for misalignment tolerance. To account for the track’s dimensional tolerances and to avoid track hardware, teams are prohibited from entering the keepout zones denoted by the crossed boxes in Figure 3. The keepout zones apply for the entire length of the track. The end of the track will feature sandbags as an emergency crush zone in case of pod braking failure.

Figure 1: Waterloop Semi-Permanent



Test Track Dimensions (in inches)

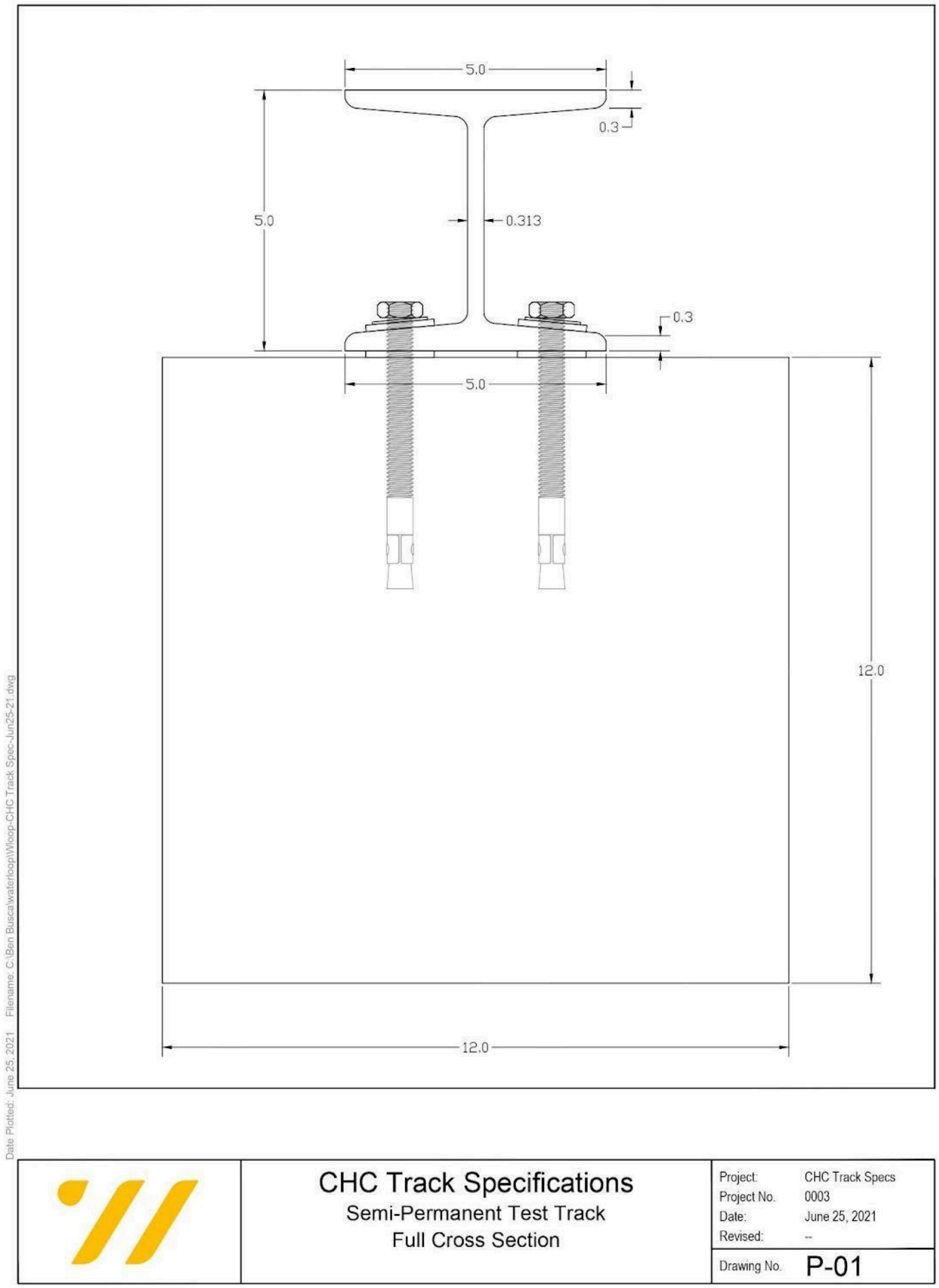



Figure 2: Waterloop Semi-Permanent Test Track Beam Cross Section

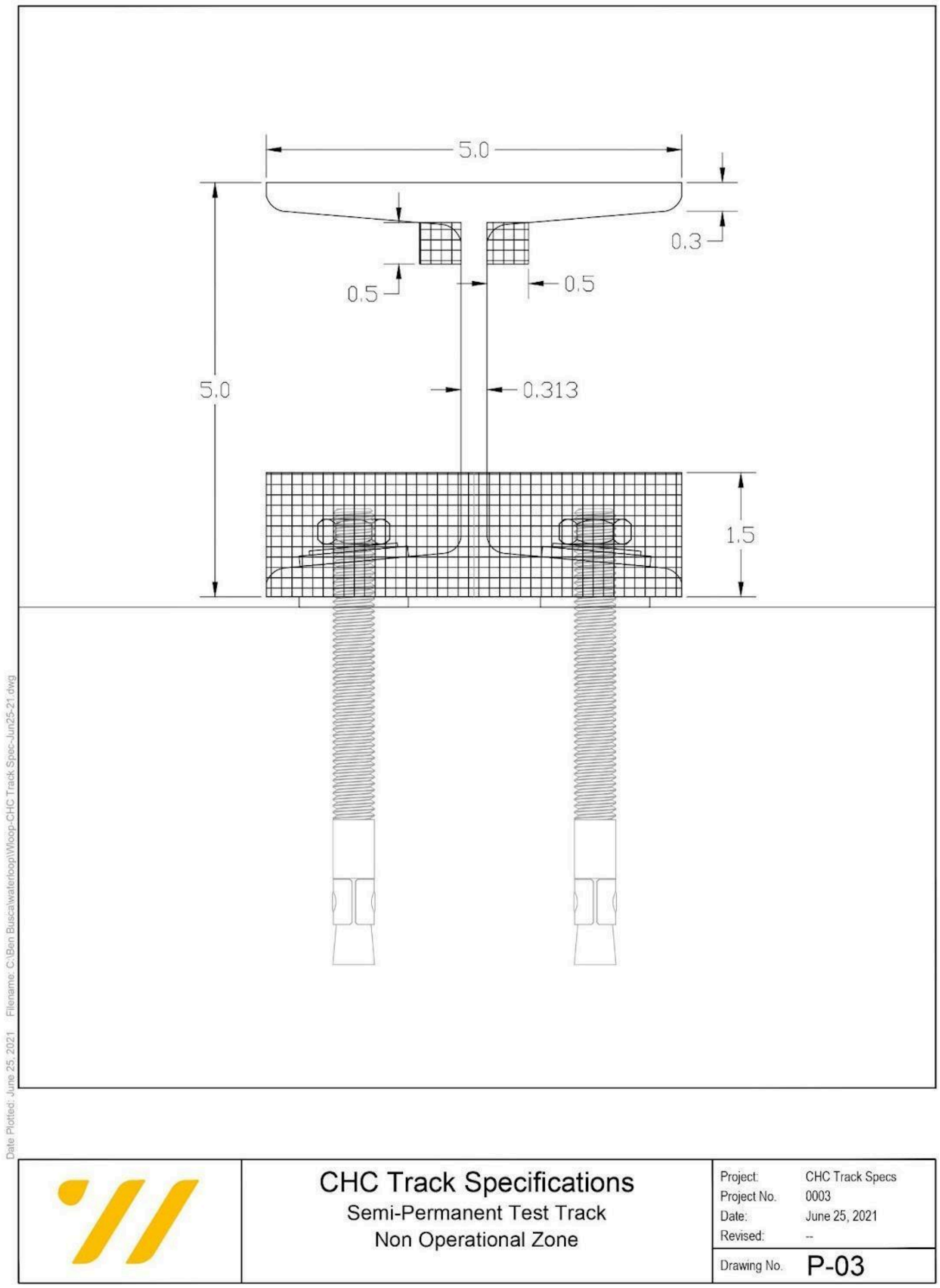



Figure 3: Waterloop Semi-Permanent Test Track Non-Operational Zone

An orthographic view of the Waterloop Semi-Permanent Test Track is visible in Figure 4.

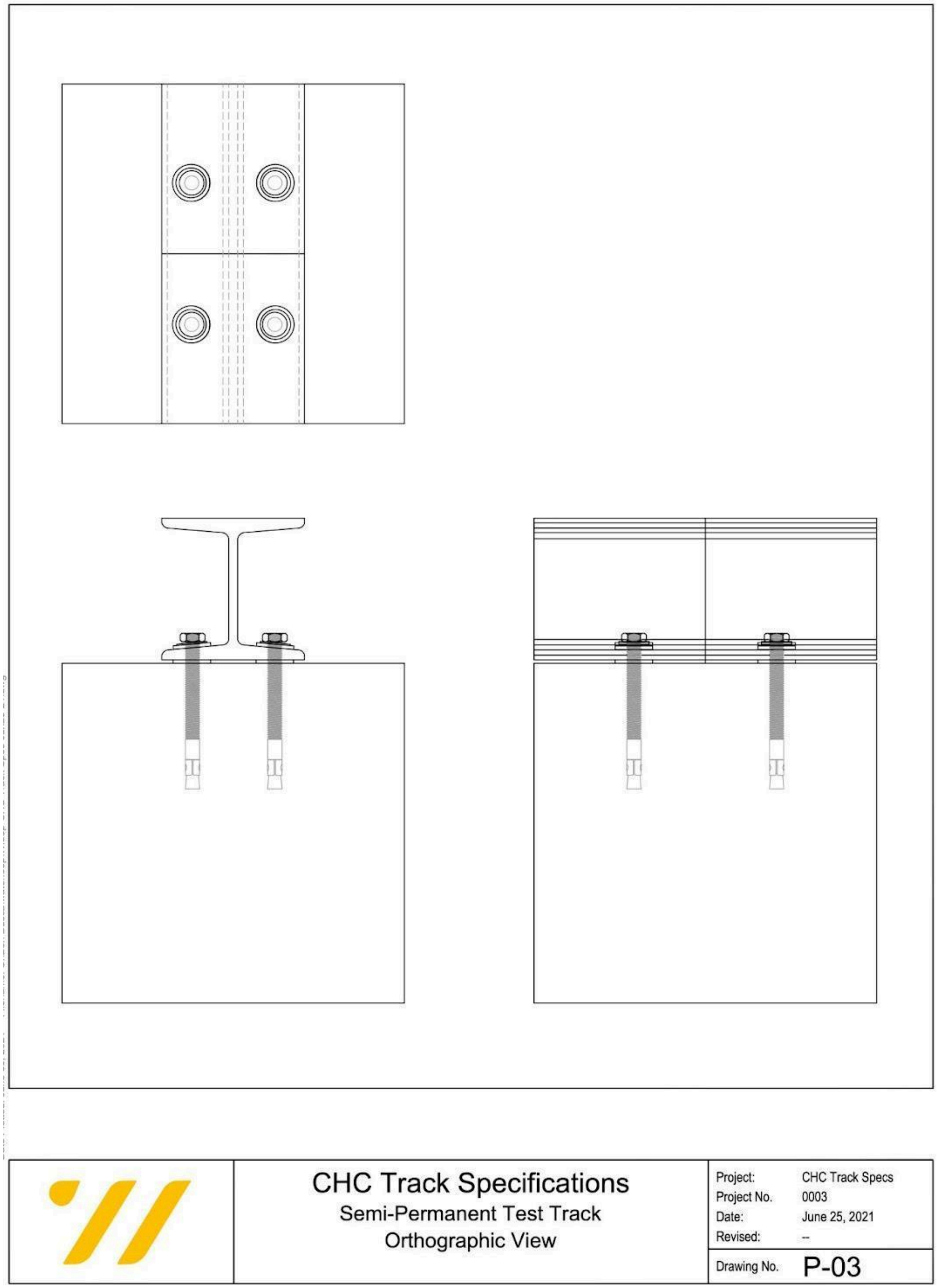



Figure 4: Waterloop Semi-Permanent Test Track Orthographic View

A render of a segment from the Waterloop Semi-Permanent Test Track is visible in Figure 5.

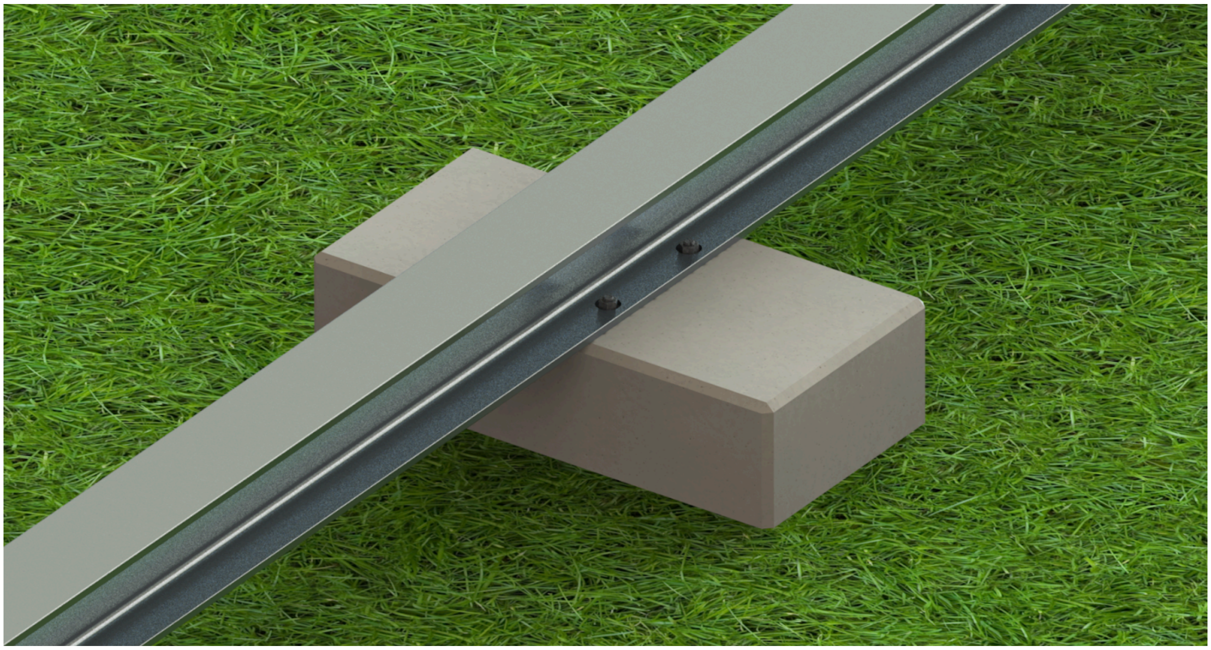


Figure 5: Waterloop Semi-Permanent Test Track I-Beam Segment

### 3.4.2 Clearance zones

To ensure the safety of spectators, a minimum track zone of 5 metres will be established around the track from which spectators are prohibited from entering. The track zone, pod loading and unloading zones, and workstation are visible in Figure 6.

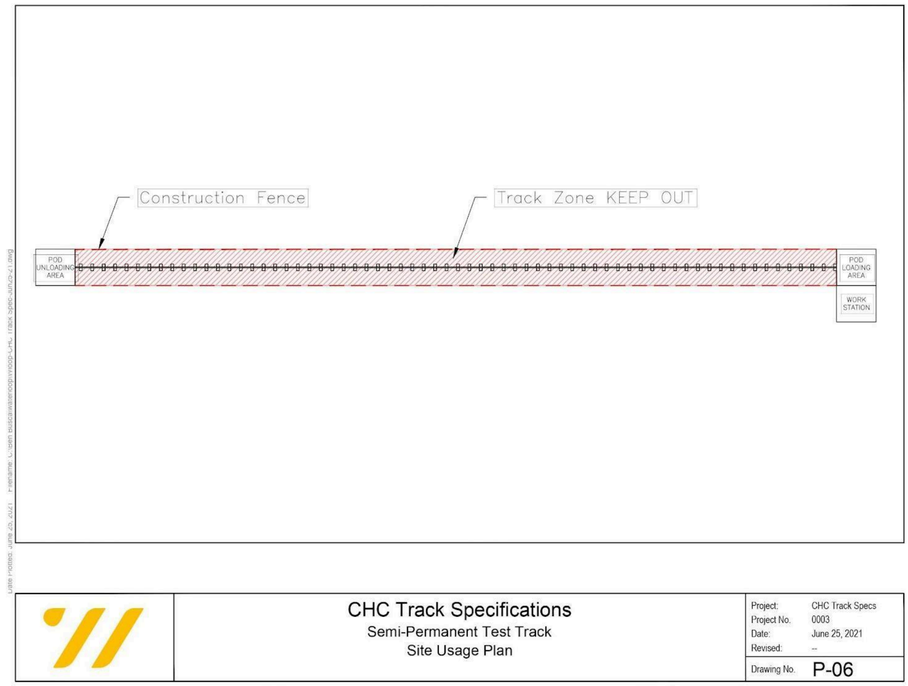



Figure 6: Waterloop Semi-Permanent Test Track Site Usage Plan

# 4. Rules for Subsystem Design

## 4.1 Structures/Chassis

Pods SHALL NOT:

1. Exceed a mass of 236 kg nor exert a downward force greater than 2315 N on the track at any point during operation. Levitating pods must also adhere to this limit.
2. Exceed 3 meters in length. There is no minimum length requirement.
3. Have any exposed or loose wires. All electrical subsystems must be enclosed, and wires shall be sufficiently secured.
4. Have loose fasteners. All fasteners must be in good condition and be properly installed. Torque specifications and torque stripes are highly recommended for critical connections (both mechanical and electrical).
5. Have any sharp external protrusions.
6. Damage the I-beam track through plastic deformation, excessive wear, corrosion, or fracture.
7. Cause the track to overheat past 150℃ during operation.
8. Extend outside of the clearance zone or below the track during operation.

Pods SHALL:

1. Be resistant to vibrations, derailing, torsion, and other deformations through FEA, physical tests, and/or test runs.
   - Positive locking mechanisms such as lock washers or blue loctite are highly recommended to resist vibration, but not required.
   - Stress analysis is recommended to ensure that components of the pod will not fail due to stress from torsion, shear and bending under normal loading conditions and operations while applying a safety factor of 2 at minimum.
2. Maintain a minimum safety factor of 2 for all force, acceleration, and speed requirements during operation through FEA, physical tests, and/or test runs.
3. Have calculated the combined TNT equivalent of all pressure, spring, and electrical systems on the pod. This will be used to determine the minimum clearance zone around the track during operation.
4. Have a center of mass that lies on the center of I-beam's top flange.

**4.2 Braking**

A robust braking system is critical to ensure the safety of the event. To minimize damage to the track brakes must:

1. Be blunt and not scratch, damage, or overheat the track past 150℃ when engaged.
2. Have a Brinell hardness less than 85 HB for physical braking pads.
3. Not apply an instantaneous pressure of more than 34 MPa at any point.
4. Be capable of automatically deploying and stopping the pod in case of any failure modes (power, system, pressure, thermal, communications, etc).
5. Be dimensionally tolerant of all potential variations and defects in the track.
6. Adhere to the braking configurations shown in Figure 8.
7. Do not use aerobraking.

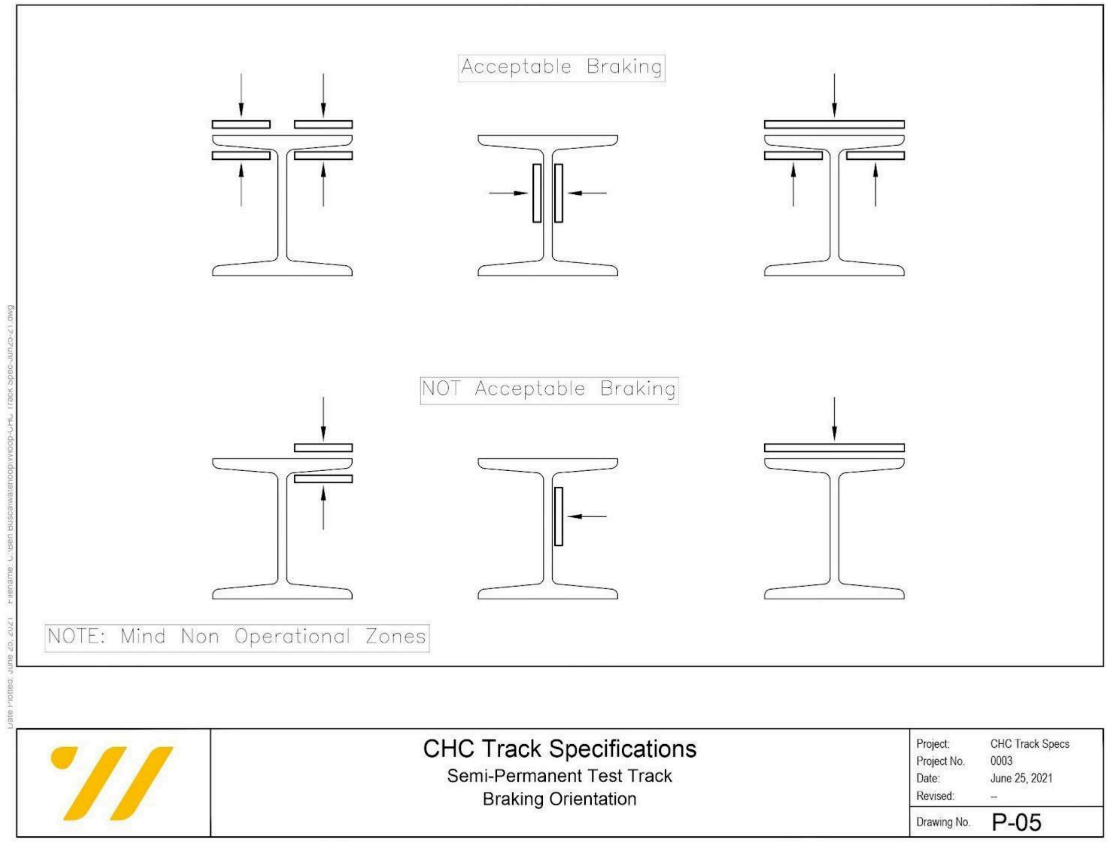



Figure 8 : Acceptable and Unacceptable Braking configurations

### 4.3 Aeroshell

1. Every pod shall have an aeroshell that sufficiently protects the pod against wind, dust particles, other aerodynamic forces and atmospheric conditions expected at the maximum operational speed of the pod.
2. It should be proven that the method of attachment of the aeroshell to the chassis of the pod satisfies the requirements for safe operation.
3. The track is at an airport and crosswinds are expected, so the aeroshell design must also take into account this factor.
4. The aeroshell requirements may vary with the speed of the pod. For example, a pod with a top speed of 100 km/h should have a better aeroshell than one with a top speed of 5 km/h. It should explicitly be proved by the team that their aeroshell is equipped to handle all conditions which arise at maximum speed of operation of the pod.

### 4.4 Pressurized Systems

1. All gasses used must be non-flammable.
2. Self-made pressure components (vessels, cylinders, piping components are prohibited. Purchased pressure vessels and components cannot be fundamentally modified and must be CSA B51, ASME Section VIII-1 Code or equivalent certified.
3. Pressurized systems must have constant pressure monitoring using digital pressure monitoring systems complying with CSA B51 within the sampling rate from 1-1000Hz. This information should be displayed both on the pod and relayed to the team desktop.
4. If the maximum allowable working pressure (MAWP) is surpassed in any pressurized system, emergency procedures must be taken to decelerate the pod to a full stop and an automatic release valve mechanism must be activated to release the pressure immediately.
5. Pressurized systems must be immobile when subject to rotations, vibrations, and collisions experienced during normal operation of the pod.
6. Pressurized systems must be isolated from any heat sources.
7. Pressurized systems should be leak tested at their maximum allowable pressure (MAP) for 5 minutes with a pressure drop of no more than 5% or 100 kpa (whichever is smaller) 0 psi and then depressurized to verify functionality.
8. An automatic pressure release valve is required for each pressurized system to relieve pressure at the MAWP.
9. Pressure regulators are required to limit the output of each pressurized system.
10. A manual release valve(s) must also be present at each pressurized system to depressurize it and accessible at all times without the need to remove the aeroshell.

### 4.5 Cooling Systems

Teams that use cooling systems must:

1. Ensure that their coolant will not come in contact with any electrical devices in the competition zone.
2. If using liquid cooling, either use water only or ask the Hyperloop Global Technical Team for special approval to use (other than water or air) di-electric coolants. For the latter, the team is responsible for cleaning up any spills that occur in the competition area.
3. Provide material safety data sheets for dielectric coolants if used.
4. Have sufficient sealing that liquid leakage is prevented.

    a. Teams are recommended to test the effectiveness of sealing by rotating the liquid enclosure about the XYZ axis or by hydrostatic pressure test.
5. Pressurized cooling systems are subject to all the regulations mentioned in the pressurized systems section. In particular, automatic and manual release valves are required for pressure relief.

### 4.6 Guidance

Any components that directly contact the track at any time of run are considered guidance components. All pods must prove that they have:

1. Excellent mechanical fit with the track through detailed tolerances, material specifications, and CAD models of the contact points mounted to the track.
2. Adhere to the Non-Operation zones detailed in Figure 3.
3. Wheels (if present) that adhere to the configuration shown in Figure 7. Vertical symmetry across the guidance system is highly recommended but not required if the system is proven to be stable through physical test runs.
4. If wheels are present, they must be accessible for inspection when not in operation.
5. A suspension system that resists vibrations, torsion, and other forces during operation. This applies to both levitating and non-levitating pods.
6. If springs are involved in the system, they should be designed with a minimum factor of safety of 2.
7. Measures should be taken to ensure that the springs don't come off loose positions during operation.
8. Information about any preloading of springs should be clearly stated and justified.
9. Information regarding the behavior of the guidance system when introduced to a vibration should be clearly stated in the documentation.

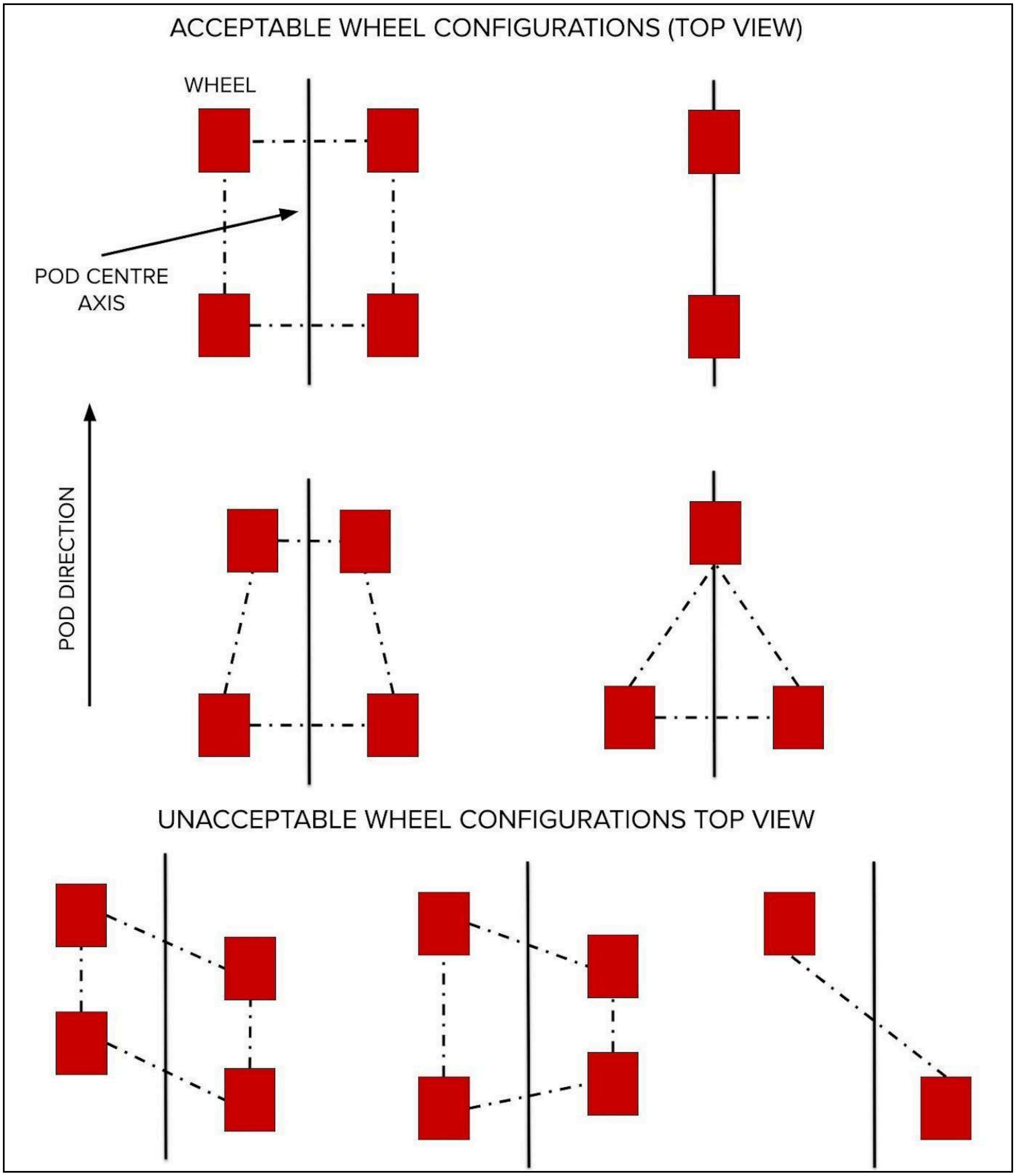



Figure 7: Hyperloop Global Wheel Configurations

## 4.7 Electronics

A robust software, controls and communication design is critical to ensure a safe and predictable behavior of the pod.

### 4.7.1 Software

1. For critical tasks and signals, teams must ensure that the failure of a single component does not lead to a catastrophic failure (e. g. digital signals using watchdogs, analog signals via value range, short circuit leads to implausibility).
2. Teams must ensure that main software components (critical tasks) react to both expected and unexpected inputs with a defined and stable output.

### 4.7.2 Controls

1. Teams must provide runtime profiles detailing acceleration, deceleration, and steady speed zones during runtime on the track. This includes the distance at which the maximum speed is expected to be reached so that an external speed sensor may record the pod speed.
2. The maximum pod acceleration and deceleration is 50 $m/s^2$, however in emergency situations the maximum deceleration must not exceed the temperature limit and structural integrity of the pod.
3. Pod's that decelerate above 10 $m/s^2$ must prove through calculations, simulations, or test runs that their brakes can withstand the temperature increase, and that the track temperature does not increase past 150℃.
4. All pods must have a method of measuring position, speed and acceleration.
5. All motors must be controlled via a motor controller. Feedback control loops are recommended; however, open loop configurations are acceptable if previously tested.
6. All pod data, sensor information, and communication logs must be recorded at a reasonable rate in persistent memory onboard the pod. Access to this persistent memory may be requested by Hyperloop Global officials.
7. All pods must indicate basic health information through an LED interface on the exterior with sufficient brightness for visibility under sunlight when the observer is within 2 meters. At minimum, pod's must indicate:
    a. Battery health: blinking RED if malfunctioning
    b. Other errors: constant RED
    c. Standby (main power off): blinking YELLOW
    d. Moving (main power on): solid GREEN
    e. Braking and coasting (main power on): blinking GREEN

8. Teams are required to create a pod state diagram with detailed conditions and responses for all potential states that the pod may be in. The pod should never be in an unknown state.
9. Teams are required to explain the conditions that lead to a state transition from the state diagram, including error conditions and expected outcomes.
10. Teams must validate the sequence of actions following the detection of a catastrophic error until a safe state is reached (e.g., what happens when the drivetrain throws an error, what shuts down first, etc.)
11. Teams must show how the individual computing units of the pod (“nodes”) are physically connected and which communication methods are used.
12. This overview shall show which node is responsible for a particular (critical) task as well as how critical signals are distributed.

#### 4.7.3 Communications

A network interface at the Hyperloop Global event site will be set up so that pods can communicate with a base station. For communications between the pod and the base station the following guidelines must be met:

The base station must display relevant information about the pod in a convenient format (e.g., display average battery temperatures instead of each cell temperature). However, if a parameter is no longer within acceptable limits, that data should be the primary viewpoint of the operator. Teams are responsible for deciding which parameters to relay to the base station; some example key specifications include but are not limited to:

a. Voltage, current, and temperature for critical components belonging to the motor controller and motor.
b. Battery voltage and current, state of charge
c. Target speed, current speed, acceleration, position, and pressure

The base station must have a physical emergency stop button that can relay a stop command to the pod at the user’s discretion.

d. Hyperloop Global officials reserve the right to manually abort a team’s track run. The emergency stop button must be accessible to Hyperloop Global officials at all times while the pod is in operation.
e. When the emergency stop is activated, the pod should:
    i. Exit any propulsive state the pod may be in
    ii. Engage standard braking systems and switch to a braking state.

Communication between the pod and base station must be wireless. Two options are available for communications at the test track:

f. Use of a radio (operating frequency between 902 MHz to 928 MHz to transmit directly to the base station) - teams will provide their own radios.
g. Wi-Fi connection on a secure 2.4 GHz network
    i. Hyperloop Global will provide the network.

ii. IP addresses will be statically assigned. All teams will get an individual address given to them each for one base station and one pod. These will be given at the event.

During the conference, while another team is running their pod on the track, all other transmission devices should be disabled, and pods/base stations should be disconnected from the network to not interfere with the active pod's communications. In the event that the pod loses continuous connection with the base station, the pod should automatically abort the track run and start a predetermined braking procedure.

**4.8 Propulsion**

Pods that make use of powertrains or rotating motors must adhere to the following criteria:

iii. There is no limitation to the type of powertrain used, however, any mechanical power transmission devices must be confined in a solid enclosure that prevents part dislocation in the event of failure.

iv. Mechanical power transmission enclosures should be monolithic; if composed of separate components, the maximum allowable gap is 3 mm.

v. Mechanical power transmission enclosures must demonstrate that they are capable of withstanding the force impacts of any moving components within the enclosure. In particular, rotating belt drives and chains should be contained within the enclosure even if dislocated at top speed.

vi. Load testing should be performed and recorded to ensure proper function at maximum speed. This can also be used to test thermal impact on the electrical system.

vii. The enclosure will be inspected by Hyperloop Global as part of the safety check prior to the demonstration. This is to ensure that the enclosure is properly installed and will not fail due to any unforeseen circumstances.

**4.9 Levitation**

1. The downward force exerted by the system along with weight of the pod should not be greater than 2315 N
2. Teams should ensure that any permanent magnets used are properly secured and don't come off during runs.

3. Teams need to prove that any permanent/electromagnets do not affect the functioning of any other component/subsystem of the pod.
4. If the magnetic field from permanent magnets /electromagnets interferes with the track, it should be proved by the team that this will not cause any temporary or permanent damage to the track.
5. Magnets should be stored away safely in appropriate containers when not in use.
6. Appropriate warning signs should be placed near magnetic components.

### 4.10 Power systems

1. All pods must be electric and powered through electrochemical cells or renewable energy (batteries, fuel cells, air pressure). Gasoline, biofuel, and other non-electric power sources are prohibited.
2. All battery cells must be suited for the pod's application as per manufacturer specifications. This includes ensuring that voltage and current discharge rates are never exceeded.
3. Self-made battery cells are prohibited and purchased battery cells must be from manufacturers that are UN38.3 or ISO certified or equivalent.
4. Battery packs must prevent cell dislocation when subject to rotations, vibrations, and collisions experienced during normal operation of the pod.
5. The pod's power on/off mechanism must be capable of engaging and disengaging the high side and low side contactors to completely isolate the battery from the drivetrain.
6. At least one E-STOP switch that is accessible from outside the pod and clearly labeled should be placed to terminate power to the pod by disengaging the contactors [Figure 8].
7. A battery management system (BMS) must be implemented to monitor battery pack health and power off the pod if necessary.
8. Minimum Protection Features
    a. Overvoltage and undervoltage
        i. The BMS must monitor the voltage output of the battery pack and cells. In case of overvoltage or undervoltage the BMS must disengage the contactors.
        ii. Additional components such as diodes, potentiometers, and voltage regulation circuits are recommended.
    b. Overcurrent
        i. Fuses should be placed between each of the battery packs and contactors on the high side and low side.
        ii. The BMS must monitor the continuous current of the battery pack and disengage the contactors in case of overcurrent. The BMS must

also monitor the state of charge and ensure the battery charge is not depleted.

c. Over temperature
    i. The BMS must monitor the temperature of at least 25% of the cells for high voltage and relay this information to the desktop. There is no minimum requirement for low voltage.

d. Reverse polarity
    i. All connectors should be keyed such that high voltage and low voltage lines cannot fit into the same connector or be connected in the reverse direction.

e. Transient circuit protection
    i. There are no strict requirements for transient protection, however, teams are expected to account for this in their designs.

2. A pre-charge and discharge circuit is required for high voltage systems to restrict current through components. Teams must calculate the duration of time the circuits need to be active before the contactors can be reengaged.
3. A manual disconnect service plug is required to disconnect the battery. It is recommended that it is placed between the battery cells, however, it is acceptable to place it between the contactor and the battery pack on the high and low side.
4. Battery packs must account for battery expansion to ion and be electrically grounded.
5. Low voltage battery packs must be galvanically isolated from high voltage battery packs.
6. Teams are responsible for bringing fire extinguishers that are suited for use on the chemistry of their particular batteries.
7. Teams are required to perform thermal testing on cells to verify expansion and functionality.

viii. Wiring

1. Wiring color must follow Wiring Colour Code Schema [Figure 9]. High voltage DC must have at least one marking if it cannot be placed every 30 cm. If wiring is not the correct color electrical tape can be used. Electrical tape should be used for marking DC high voltage.
2. Any wires that carry a nominal voltage greater than 48 V are considered high voltage wires.
3. High voltage and low voltage wires must be tied separately and have different connector heads.

4. High voltages wires must be grounded to the ground of the battery and cannot be grounded to the chassis. Low voltage wires should be grounded to the chassis.
5. An insulation monitoring device (IMD) must be used to ensure that the high voltage rail remains isolated from the chassis. This IMD should be placed before the contactors and main fuse, however, a secondary fuse should be placed on the high voltage input line to the IMD.
6. High voltage and low voltage systems must be electrically isolated from each other.
7. Wire insulation must be rated for the expected temperature, voltage, and current.
8. Thermal pads, heat sinks, and other thermal management techniques are recommended for additional temperature insulation.
9. Net ties, cable ties, and other wire management tools must be implemented to prevent loose, mobile, or hanging wires between connections.
10. Custom high voltage PCBs must be IPC-2221 compliant. In particular creepage distance must be kept equal or greater than clearance distance.
11. The acceptable power delivery circuit configuration is shown below.

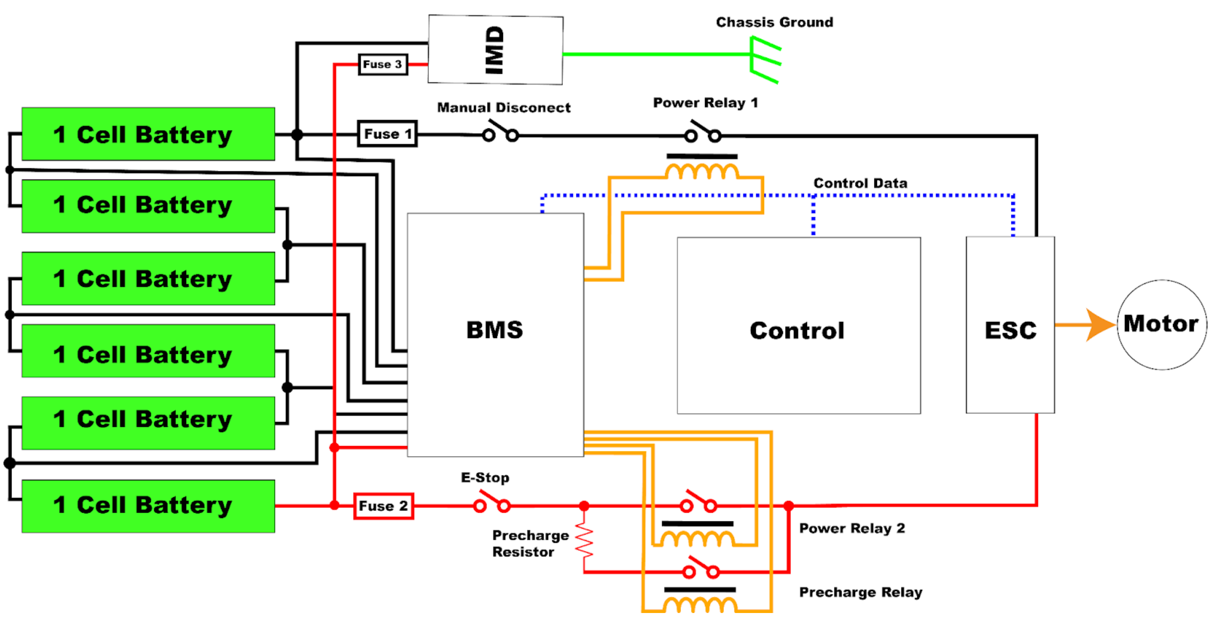



Figure 8: Acceptable power delivery circuit

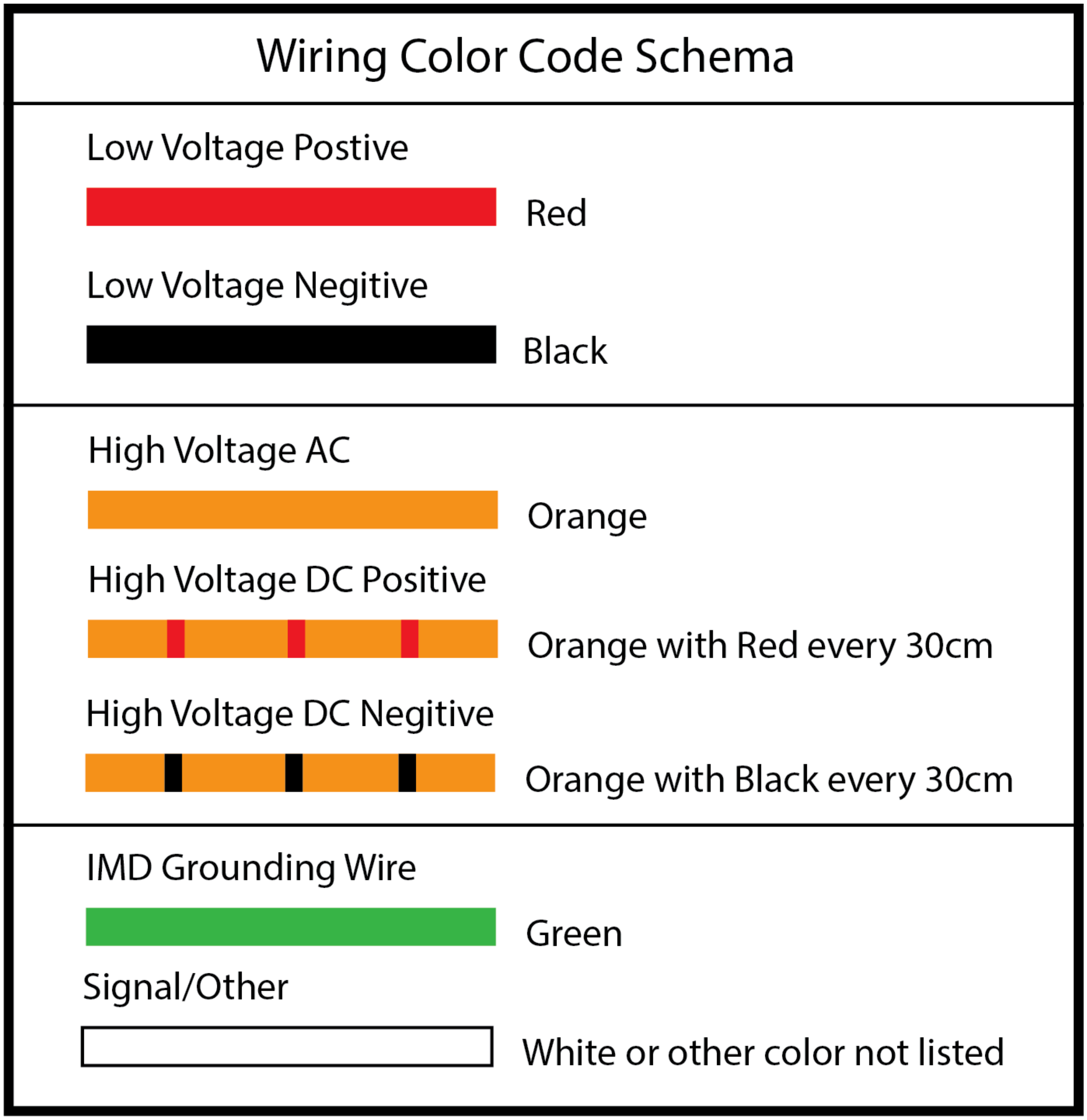



Figure 9: Wiring color code schema

## 5. Testing guidelines

The following section provides a reference for testing of manufactured systems. Tests are to be designed and done by the teams but should provide at least the following things noted for each of the sections. Hyperloop Global holds the right to ask the team for specific tests if required. Appropriate time will be allocated to the team to present the results of such tests. The teams need to prove that the systems manufactured are the same as intended in the designs and that they function as expected.

### 5.1 Structure/Chassis

Test should be performed which prove:

a. That the chassis is capable of enduring all forces imparted it during run
b. That the components are securely mounted on the chassis and will not fall off the chassis during run

### 5.2 Braking

Test should be performed which prove :

a. The braking system is fail safe
b. The brakes actuate in case of any power failure on board.
c. The brakes actuate in case of a communication loss between the pod and base station.
d. The system is capable of braking the pod while leaving a safe distance as a buffer on the track.
e. No parts which are in contact with the track will cause any wear/deformation of the track.

### 5.3 Aeroshell

Test should be performed to prove the following:

a. That verify the results obtained from the CFD analysis (e.g., wind tunnel test)
b. That the aeroshell is securely mounted on the pod and will not detach from the pod during run

### 5.4 Pressurized systems

Test should be performed to prove that:

a. Constant monitoring of the pressurized components is carried out in the system.
b. There are no leaks in the system.
c. The system enters a safe state during events like sudden power cutoff and loss of communications.
d. Pneumatic systems hold enough pressure to bring the pod to a safe stop.
e. The correct and successful working of the automatic release valve

### 5.5 Cooling System

Test should be performed which prove:

a. There are no leaks pertaining to liquid or gaseous cooling circuits.
b. The cooling system manufactured works in sync with the calculations done in the design process.
c. Testing guidelines mentioned for pressurized systems apply for cooling components if coolant (liquid or gaseous) is pressurized while working.

### 5.6 Guidance

Test should be performed which prove :

a. That the guidance system works as intended and stated in the FDP
b. That the system is able to dissipate all energy imparted due to an undulation in the track.
c. That the system is capable of keeping the pod on the track even at highest speed of run
d. No parts that are in contact with the track will cause any wear/deformation of the track.

### 5.7 Electronics

All states of the pod should be tested including emergency situations.
They can be simulated by whatever means as long as the state flow diagram matches up with real world testing.

Proof of functional emergency systems is required through the technical submissions. This is to ensure that all pods can run safely during demonstrations.

### 5.8 Propulsion

The test performed should prove :

a. Working of the propulsion system as intended in the design.
b. The correct working of the propulsion system in both loaded and unloaded states.
c. The vibration produced during operation (if any) of the propulsion system can be handled by the pod.
d. The LIM (if used) does not interfere with any communications while working.

### 5.9 Levitation

Test should be done to prove:

a. The system doesn't heat the track to such an extent that it causes damage to the track.
b. All components (if rotating or moving) are secured and do not possess any chance of coming loose.
c. While the magnetic/electromagnetic systems are in use they do not interfere with other parts of the pod including but not restricted to the communication and electronic components

### 5.10 Power systems

- Test should be performed to prove:
    a. The system goes into a safe state when a failure occurs in the pod.
    b. The correct working of the manual E-stop.
    c. The system does not excessively heat up when working at the limits if its operation range (e.g., max voltage)
- Teams should provide data about voltage, amperage, temperature generated during a test simulating the actual run of the pod.