FDD Guidelines

Edition 2025

European Hyperloop Week

Tech Committee

March 9, 2025

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Foreword

Dear Participants,

This document intends to give teams a better understanding of the expected deliverable of the Final Demonstration Documentation (FDD). It is a guide for teams to follow when writing the document so that all required information is present. Following the advice in this document will facilitate the application process since this contains all the information the jury would like to know from the teams' demonstration. It is therefore strongly advised to follow the structure presented in this document.

Please be mindful that the jury committee is formed by experts of the industry and they already possess knowledge on basic concepts. It is not necessary to explain what a linear motor is, or to justify the formulas used if they are already a standard in the industry. Instead, use your pages wisely to describe why your system is different, what your design concerns are and how you have solved them.

Bear in mind that expert jurors on specific topics will review each section independently. So a juror specialized in mechanical engineering will only read the mechanical section, a juror specialized in software will only read the sense and control section, etc. For this reason, in this deliverable, we ask you to include the suspension and safety wheel systems on the mechanical subsection and leave the levitation section for magnetic levitation systems.
This document will be used by the jurors to evaluate teams for the Engineering Design Award. Therefore, teams are encouraged to present their pod in the most compelling and persuasive manner possible.
Best regards and good luck!

The EHW Technical Team

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Contents

March 9, 2025, the EHW Committee

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1 Cover Page

Teams are required to include a cover page at the beginning of their submission. The cover page must contain the following information:

- Title ”FDD - Final Demonstration Document”
- Team Logo
- Team Name
- Institution/Organization/University
- Submission Date

Ensure that the cover page is clear and professionally formatted. You are encouraged to design the cover page creatively, so it aligns with your team’s theme.

2 System

For simplicity and ease of reviewing all the documentation, the following structure is recommended for the section:

2.1 System Overview

In this section, you should especially focus on the top-level description and decisions of your system. You should shortly touch on the aspects which your design is revolved around. If available, include the requirements or constraints that have influenced your design the most. Furthermore, include a short budget estimation for the project as well as the following values for your vehicle if possible:

- Render of the vehicle CAD.
- Weight and size.
- Distribution of subsystems inside the prototype.
- Mass distribution of the prototype.
- Acceleration profile of the demonstration.
- Budget divided by subsystems.
- Can the system be scaled for a full-scale model? What adaptations would be necessary? Describe this in general terms, you do not have to go into specifics like the size of the wheels should be bigger.
- If applicable, the same information about the track.

Please include a short description of how the system will be transported to the EHW location. Note that teams applying with a subsystem application will need to describe all the subsystems, even those that will not be evaluated.
Include also the following table, to give an overview of the systems used.

System Overview	
Length [m]	-
Width [m]	-
Height [m]	-
Weight [kg]	-
Vertical levitation method	(e.g. HEMS)
Vertical levitation system max. current [A]	-
Lateral levitation method	(e.g. EMS)
Lateral levitation system max. current [A]	-
Motor concept	(e.g. LIM)
Motor max. current [A]	-
Regenerative braking used	Yes/No
LV system max. voltage [V]	-
HV system max. voltage [V]	-
Braking method	(e.g. Pneumatic activated friction pads)
Pneumatic system max. pressure [bar]	-
Data Log Frequency [Hz]	-
Board communication protocols	(e.g. CAN, Ethernet)

Table 1: System overview methods

This section should occupy a maximum of 15 pages.

2.2 Mechanical

In this section, the main components of the mechanical system shall be described as well as their basic functionality. Do not explain basic physics or commonly used subsystem functionalities unless required by the jury in a feedback document. This section should at least include, if applicable:

- Chassis (or mechanical structure holding prototype together)
- Suspension
- Braking system
- Aeroshell (if applicable)
- Custom track (if applicable)

  Teams may include additional subsystems (e.g., vacuum chamber) in the mechanical section if they consider it necessary to list them as separate subsystems.

Since the mechanical section may include multiple subsystems, please address each subsystem separately, following the proposed structure below:

1. Introduction
   (a) Provide a description of the subsystem with its functionality.
   (b) Include a table with the subsystems key components and key characteristics. The following illustrates an example:

Suspension				
Component	Wheels	Axles	L-bracket 1	L-bracket 2
Number [-]	x8	x8	x16	x8
Mass [kg]	1	0.2	0.1	0.2
Size [mm x mm x mm]	ø 100 x 50	ø 10 x 90	20x30x50	30x40x60
Material	Polyurethane	Duplex Steel	Aluminium 7075	Aluminium 7075
Manufacturing process	Injection molding	Lathing	Milling	Milling
In-house/outsourced	Outsourced	In-house	In-house	Outsourced

Table 2: Example of key components list for suspension

2. Overview
   (a) Similar to Section 2.1, provide a detailed overview of the subsystem. Include a graphic (either a picture or a CAD image) along with a description of its contents, ensuring it accurately represents the entire subsystem.
   (b) Describe how the subsystem is integrated with the pod, including the connection method.
3. Design process and appearance
   (a) Present CAD models and technical drawings.
   (b) Provide relevant properties of the materials selected.
   (c) Provide a rationale for why the specific configuration has been chosen.
4. Manufacturing process

(a) Explain the measures taken to ensure the designed part is realistically manufacturable. For example, brackets were designed without outer circular segments to allow milling, or the part consists of flat sheets to facilitate laser cutting.

(b) Describe the manufacturing steps taken and provide justifications for each. Additionally, offer insight into the team's planning for complex parts and how they overcame manufacturing challenges.

5. Integration process

   (a) Explain the assembly process of the parts, including their integration into subordinate structures or systems, if applicable.

   (b) If applicable, explain in detail how the subsystem interacts with the other subsystems.

6. FMEA (Failure Mode and Effects Analysis)[1] results in discussion

   (a) Provide reasoning and the necessary calculations to justify the simulated loads.

   (b) Prove details on the type of mesh and the specific boundary conditions used in your simulations

   (c) Provide evidence of simulations validating theoretical assumptions and analyze results.

   (d) What safety factor was applied and have requirements been met?

   (e) Assess whether the system is structurally designed to withstand impacts.

7. Demonstration

   (a) It should be outlined how the system will be demonstrated if it is a standalone system.

8. Full-scale adaptation

   (a) Describe how this subsystem choice benefits a full-scale concept or how it should be adapted for implementation in a full-scale Hyperloop system.

9. Additional considerations when writing the document for specific subsystems:

   Braking system

   (a) Identify possible failure points.

   (b) In case several braking systems are used, include a thorough description of when each of the braking systems will be used.

   (c) Describe the braking mechanism, including calipers, discs, and any additional components. Provide reasoning for the selection of specific components.

   (d) Explain the method of actuation for the braking system (e.g., hydraulic, pneumatic, electric).

   (e) Include details of the braking force distribution and how it ensures stability and control.

   Pneumatic system

   (a) Include pneumatic circuit diagrams and specifications.

   (b) Justify the design of the pneumatic circuit by analyzing potential failure points and explaining the placement of key components. Ensure that each design decision is supported by functional and safety considerations.

   (c) Provide details on the pneumatic actuators used and their specifications.

[1] For more information on how to develop an FMEA: https://quality-one.com/fmea/

(d) Discuss the pressure requirements and how they are regulated within safe limits.

(e) Outline the control mechanisms for the pneumatic system and how they ensure precise operation.

Aeroshell

(a) Include CFD analyses for the conditions expected during the demonstration, and their results, covering values such as lift, drag, or moment coefficient.

(b) If you plan on demonstrating inside a tube, include it in the CFD simulations.

(c) In case the system uses high voltage, indicate how will the MIDs be shut off when the aeroshell is covering the pod.

Custom track

(a) Include a detailed plan outlining the construction of the custom track and the measures taken to ensure the precise placement of individual track components.

(b) Address topics such as thermal expansion, weather resistance, ground anchoring, regulation, and electrical grounding to ensure that the infrastructure can withstand weather conditions safely if necessary.

(c) Detail the track type (e.g., external track, tube-like structure...)

(d) Include a timeline, requested equipment, days and times when a forklift will be required as well as the number of people that will be working on the Custom Test Track simultaneously.

Vacuum tube

(a) Include how vacuum is going to be achieved.

(b) Detail how sections are going to be joined to prevent leaks.

This section should occupy a maximum of 15 pages. This is increased to 20 pages, if a team brings a custom track.

2.3 Traction

In this section, the main components of the traction system shall be described as well as their desired functionality. Do not explain basic physics or commonly used subsystem functionalities unless required by the jury in a feedback document. This section should include, if applicable:

- Motor
- Track interface
- (Regenerative) braking

Below is a proposed structure with what should be included per section, as applicable:

1. Introduction
   (a) Besides a description of the overview of the system, outlining the type of motor, please also include the main characteristics of this subsystem in a table. The following illustrates an example:

Traction System	
Maximum acceleration [g]	-
Maximum deceleration [g]	-
Operating voltage [V]	-
Nominal current [A]	-
Maximum current [A]	-
Maximum power [kW]	-
Dimensions [m x m x m]	-

Table 3: Traction system characteristics

If applicable, the following information should be included about the motor. The first two sections are mandatory, for the other sections it is up to the team to decide if they want to include it. The chosen information should highlight why they think they have designed a good subsystem.

2. Overview
   (a) Explain the main requirements and constraints that drive the design, such as:
      - Maximum design speed (should be higher than the demonstration one).
      - Average acceleration.
      - Dimensions.
      - Focus (Is it efficiency, power density...).

   (b) Explain the concept of the motor. If necessary, explain briefly why the concept was chosen over other possibilities and how that makes your motor fit your application.
   (c) Detail the size, components, and appearance of the motor. Also include the choice of material, mass, dimensions, and other relevant factors.
3. Design process and appearance
   (a) Present CAD models and technical drawings.
   (b) Present and justify the selection of materials used in the subsystem.

(c) Provide relevant properties of the materials selected.

(d) Provide a rationale for why the specific configuration has been chosen. Dimensions, number of windings, strength of magnets, air gap, etc.

(e) Present FEM results, including pictures and obtained values. These must include magnetic and mechanical simulations of the assembly. Magnetic simulations must include forces generated at different air gaps and currents (if applicable).

(f) Prove details on the type of mesh and the specific boundary conditions used in your simulations.

(g) Provide calculations on the expected temperature reached by the system. Discuss whether it is necessary to incorporate a cooling system (if you decide you need a cooling system, you can find an explanation in the Levitation section 11(b)). In case the motor method relies on the generation of Eddy currents to generate traction force a thermal simulation must be shown (e.g. Linear Induction Motors).

4. Control system overview

   (a) Provide an overview of the control architecture employed in the traction system to regulate the motion of the pod.

   (b) Describe the control strategy used for the electric motor, such as field-oriented control, direct torque control, or other relevant methods. Justify the choice of a control strategy based on system requirements and performance objectives.

   (c) Detail the sensors utilized for feedback in the control loop, including position sensors, velocity sensors, and any other relevant sensors. Explain how sensor data is processed and used for motor control.

   (d) Discuss the interface with other subsystems, particularly the electric system, detailing how the traction system interacts with these components to ensure coordinated motion.

   (e) Discuss the control strategy for traction force modulation, including acceleration, deceleration, and braking.

   (f) Detail any redundancy or fail-safe mechanisms implemented in the control architecture to mitigate the risk of system failures and ensure safe operation.

   (g) Detail how will regenerative braking, if possible, be achieved with the motor and what mechanisms are in place to guarantee safely recuperating energy.

5. Manufacturing process

   (a) Compile a parts list (including dimensions and mass) in tabular format, specifying whether parts are produced in-house or outsourced.

   (b) Describe what efforts have been made so that the designed part is realistically manufacturable. Example: The brackets have no outer circular segments so the part can be milled. Or the part is composed of flat sheets so they can be laser cut, etc.

6. Integration process

   (a) Describe how the parts will be assembled, including integration into subordinate structures/systems if applicable.

   (b) Explain how the motor interacts with other subsystems. For example:

      i. Sense and control: how is the motor controlled? How are failures in the motor reported to the operator?

      ii. Electrical: How is power being provided to the motor?

   iii. Levitation: Do the magnetic fields of the motor affect the levitation modules, or vice-versa?
   iv. Mechanical: How does the motor interface with the chassis?

7. FMEA (Failure Mode and Effects Analysis)[2] results in discussion
   (a) What safety factor was applied and have requirements been met?
   (b) Provide evidence of simulations validating theoretical assumptions and analyze results.
   (c) Provide an analysis of the risks of the motor.
   (d) Assess whether the system is structurally designed to withstand impacts.
8. Demonstration
   (a) Outline how the motor will be demonstrated if it is a standalone system.
9. Full-scale adaptation
   (a) Explain how this subsystem choice is beneficial in a full-scale concept or how it should be adapted for a full-scale hyperloop.

This section should occupy a maximum of 15 pages.

[2]For more information on how to develop an FMEA: https://quality-one.com/fmea/

2.4 Levitation & Guiding

In this section, the main components of the levitation & guiding systems shall be described as well as their desired functionality. Do not explain basic physics or commonly used subsystem functionalities unless required by the jury in a feedback document. For example: No need to explain the basics EMS (electromagnetic suspension) works, as every year teams use this concept.
This section should include, if applicable:

- Vertical and lateral guiding systems
  - Levitation concept
  - Control architecture
  - Safety wheel design
  - Interface with motor

Below is a proposed structure with what should be included per section, as applicable:

1. Introduction

   (a) Provide a brief overview of the system, outlining the different subsystems and components compromising the levitation/guiding system. Also include the main characteristics of the subsystem in a table. The following illustrates an example:

Vertical Levitation		Lateral Levitation	
Levitation method	(e.g. HEMS)	Levitation method	(e.g. EMS)
Nominal air gap [mm]	-	Capacity [Ah]	-
Maximum air gap [mm]	-	Maximum air gap [mm]	-
Minimum air gap [mm]	-	Minimum air gap [mm]	-
Operating voltage [V]	-	Operating voltage [V]	-
Nominal current [A]	-	Nominal current [A]	-
Maximum current [A]	-	Maximum current [A]	-
Maximum power [kW]	-	Maximum power [kW]	-
Dimensions [m x m x m]	-	Dimensions [m x m x m]	-

Table 4: Levitation and Guiding system characteristics

As described in the foreword, include in this section only the information regarding levitation modules. Include suspension and safety wheel designs in the mechanical section. Each subsystem, such as the lateral or vertical levitation systems should be addressed separately. They will be referred to in this section as levitation modules. The information described below holds for each subsection. The first two sections are mandatory, for the other sections it is up to the team to decide if they want to include it. The chosen information should highlight why they think they have designed a good subsystem.

2. Overview

   (a) Explain the concept and design requirements or constraints, such as:
      - Nominal levitation air gap.
      - Maximum and minimum levitation air gap.

- Dimensions.
- Focus (efficiency, stability, etc).
- Expected loads.

(b) Explain the concept of the levitation module. If necessary, explain briefly why the concept was chosen over other possibilities.

(c) Detail the size, components, and appearance of the levitation modules. In a table the choice of material, mass, dimensions, and other relevant factors should be included, an example of a table can be seen at the end of this text.

3. Design process and appearance

   (a) Present CAD models and technical drawings.

   (b) Present FEM results including pictures and obtained values. These must include magnetic and mechanical simulations of the assembly. Magnetic simulations must include forces generated at different air gaps and currents (if applicable).

   (c) Provide a rationale for why the specific configuration has been chosen. Dimensions, number of windings, strength of magnets, air gap, current, voltage, etc.

   (d) Prove details on the type of mesh and the specific boundary conditions used in your simulations.

   (e) Provide calculations on the expected temperature reached by the system. Explain whether it is necessary to incorporate a cooling system (further explanation in 14-b). In case the levitation method relies on the generation of Eddy currents (rotating permanent magnet disks or Halbach arrays) a thermal simulation must be shown.

4. Control architecture

   (a) Include a description of the control mechanism in place to control the air gap.

   (b) Provide calculations necessary to guarantee the stability of the system (or a description of the plan to tune the control system).

   (c) Describe the control algorithms used, whether they are PID controllers, state feedback controllers, or any other control strategy. Explain why the chosen control method is suitable for the levitation/guiding system.

   (d) Discuss the sensors used for feedback in the control loop and how their output is utilized to regulate the levitation air gap.

   (e) Explain the interface with other subsystems, particularly the motor and powertrain, detailing how the control system interacts with these components to ensure coordinated operation.

   (f) Describe how errors in the levitation system are detected and handled, including fault detection and isolation strategies.

   (g) Discuss any redundancy or fail-safe mechanisms implemented in the control architecture to enhance system reliability and safety.

5. Material choice

   (a) Present and justify the selection of materials used in the sub-system.

6. Manufacturing process

   (a) Compile a parts list (including dimensions and mass) in a tabular format specifying whether parts are produced in-house or outsourced.

(b) Describe what efforts have been made so that the designed part is realistically manufacturable. Example: The brackets have no outer circular segments so the part can be milled. The length of the coil windings is limited due to the maximum length of the winding machine.

7. Integration process

   (a) Describe how the parts will be assembled, including integration into subordinate structures/systems if applicable.

   (b) Describe in detail how the subsystem interacts with the other subsystems.

      i. Sense and control: how is the control or data from the levitation system integrated into the GUI? What errors can come from the levitation system, and how are these errors handled?
      ii. Electrical: How is power being delivered to the levitation modules? What happens if power is cut?
      iii. Traction: Do the magnetic fields of the levitation system affect the motor, or vice-versa? Is the levitation system able to handle the loads expected from the motor?
      iv. Mechanical: How do the levitation modules interface with the chassis? At what distance are the safety wheels placed? How is this distance determined?

8. FMEA (Failure Mode and Effects Analysis)[3] results in discussion

   (a) What safety factor was applied and have requirements been met?

   (b) Include an analysis of the risks of the subsystem.

   (c) Provide evidence of simulations validating theoretical assumptions and analyze results.

   (d) Assess whether the system is structurally designed to withstand impacts.

9. Demonstration

   (a) It should be outlined how the system will be demonstrated if it is a standalone system.

10. Full-scale adaptation

   (a) Explain how this subsystem choice is beneficial in a full-scale concept or how it should be adapted for a full-scale hyperloop.

11. Additional considerations when writing the document for specific subsystems:

   (a) Rotating permanent magnet disk

      i. Identify possible failure points.
      ii. Explain how the spinning wheel and motor assembly will be balanced to minimize possible vibrations.
      iii. Thermal simulations of energy transferred between magnets and track, particularly looking at the temperature components reach.
      iv. The system must be checked by an external company for balancing after their transport to Groningen (The EHW will not provide this option, teams have to find it).
      v. Provide an analysis of what would happen if one or more of these rotating disk assemblies would fail.
      vi. Include a mechanism to guarantee stabilization of the rotating disk in the direction of motion.

[3] For more information on how to develop an FMEA: https://quality-one.com/fmea/

(b) Cooling system (If this was explained in another subsystem, please refer to it and explain shortly the adaptation of the cooling system to this specific subsystem).

i. Explain how the cooling system works.
ii. Explain how the cooling system interfaces with the levitation modules and/or motor. Include CAD pictures.
iii. Explain how the cooling system has been designed to keep the temperature within acceptable values.
iv. Explain how the cooling system will be prevented from leaking.
v. Provide the necessary calculations or simulations to prove the efficacy of the cooling system.

This section should occupy a maximum of 15 pages.

2.5 Electrical

In this section, the main components of the electrical systems shall be described as well as their basic functionality. This section should include, if applicable:

- Low voltage battery
- High voltage battery
- Battery management systems
- Power electronics

  Teams may include additional subsystems (e.g., wiring system) in this section if they deem them necessary as separate subsystems.

Since the electrical section may include multiple subsystems, please address each subsystem separately, following the proposed structure below:

1. Introduction
   (a) Brief overview with the main points of the HV and LV systems.
2. Overview
   (a) Explain the main requirements and constraints that drive the design.
   (b) List of all discrete electrical subsystems
   (c) Wiring diagram of the HV system
3. Electrical and mechanical design process:
   (a) Present Schematics or logic diagrams of the boards.
   (b) Present temperature simulations for vacuum conditions.
4. Description of subsystem control.
   (a) Briefly reference the control systems of the boards, which should be explained in the levitation or propulsion section respectively.
5. Interfaces with other systems.
   (a) Briefly reference the communication protocols or control mechanisms of the boards, which should be explained in the respective Sense & Control section.
6. Final system description
7. Manufacturing process
   (a) Compile a parts list (including dimensions and mass) in a tabular format specifying whether parts are produced in-house or outsourced.
   (b) Describe what efforts have been made so that the designed part is realistically manufacturable.
8. Testing
   (a) Describe the testing procedures to be included in the Safety Procedures Documentation (SPD).
   (b) Provide a preliminary testing plan, including methodology and expected results.

9. FMEA (Failure Mode and Effects Analysis)[4]
    (a) Describe the main hazards and the measures and methodologies taken to prevent them.
    (b) Assess whether the system is designed to withstand the intended current, voltages, and temperatures.
    (c) Assess whether the system is designed to withstand the expected impacts.
10. Additional considerations when writing the document for specific subsystems:
    (a) High voltage batteries
        i. Provide details on the design or choice of an IMD (Insulation Monitoring Device) and how it will be implemented in the vehicle.
        ii. Provide details on how the MID's are integrated and prove their accessibility.
        iii. Prove how the motor and braking systems are physically prevented from being actuated at the same time.
        iv. Explain how your system meets all Rules and Regulations applicable to high voltage systems.
    (b) Supercapacitors
        i. Explain how they will be discharged in case of failure of failsafe mechanisms.
        ii. What voltage levels can your supercapacitors reach? What extra protections are there in order to guarantee the safety of such high voltages?
        iii. If they will be placed in a vacuum environment. You must detail the design of a box protecting them from vacuum.
        iv. Briefly explain what would happen if one supercap blows up (they contain acid inside and can damage the pod and the infrastructure).

This section should occupy a maximum of 15 pages.

[4] For more information on how to develop an FMEA: https://quality-one.com/fmea/

2.6 Sense & Control

In this section, the main components of the sensor network and software architecture shall be described as well as their basic functionality. This section should include, if applicable:

- Sensor network
- Communication protocols and architecture
- Protection systems
- Graphical user interface

  Teams may include additional subsystems in the sense & control section if they deem them necessary as separate subsystems.

Since the sense & control section may include multiple subsystems, please address each subsystem separately, following the proposed structure below:

1. Introduction
   (a) Brief overview of all control boards.
   (b) Diagram with the connection of all boards with NAP and control station.
   (c) Brief description of communication protocols used (1 page maximum).
2. State Machine of the vehicle:
   (a) Describe the general state machine.
   (b) Describe every transition and the case of use of every transition.
   (c) Describe particularly how the different braking scenarios are handled.
3. Brief description of code architecture and class diagram (3 pages maximum).
4. For every control board/unit in the vehicle, if applicable:
   (a) Requirements of the board.
   (b) Hardware Rationale (HW design and concerns).
   (c) Firmware Rationale (Internal State machine and design concerns).
   (d) Testing and validation plan.
5. Communication and navigation:
   (a) Design Requirements.
   (b) Network Diagram.
   (c) Diagram of all sub-networks (track, vehicle, and spectators). In this part you should describe the network infrastructure for each part of the network, that is track, vehicle and spectators. For example, for vehicle, it could be how the control boards are connected with each other and which network elements are between those (switches, routers...)
   (d) For every GUI (demonstration, testing...):
      i. Picture of every tab or layer (try to keep it at 1 tab for easier visualization during the demonstration).
      ii. Design Rationale of the GUI.
      iii. Testing and validation plan.

This section should occupy a maximum of 15 pages.

3 Style

- The document shall be delivered in A4 vertical format.
- Pt11-12 font size must be used for plain text.
- Artistic freedom is given on the document layout, but we recommend to use standard fonts and Latex for document layout.

4 Contact details

As for any other questions regarding the EHW, if you have any questions regarding the FDD submissions, please send an email to technical@hyperloopweek.com with 'FDD Submission Question' as the subject.

The link to hand-in the document is this form.