SpaceX Hyperloop Pod Competition

Rules and Requirements

August 20, 2015

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1 INTRODUCTION

On August 12, 2013, Elon Musk released a white paper on the Hyperloop, his concept of high-speed ground transport. In order to accelerate the development of a functional prototype and to encourage student innovation, SpaceX is moving forward with a competition to design and build a half-scale Hyperloop Pod. In parallel with the competition, SpaceX will be constructing a sub-scale test track adjacent to its Hawthorne, California headquarters. During Design Weekend in January 2016, entrants will submit and present their Pod designs. On Competition Weekend, scheduled for June 2016, entrants will operate their Pods within the SpaceX test track.

This document outlines the competition logistics and rules and is meant to augment, and in some cases supersede, the initial competition announcement document released in June 2015. An additional update will be issued with the tube specifications in September 2015.

For an updated competition schedule, visit www.spacex.com/hyperloop.

Note: This competition is a SpaceX event. *SpaceX has no affiliation with any Hyperloop companies, including, but not limited to, those frequently referenced by the media.*

Any questions or comments can be posted on the Hyperloop Forum at http://tx.ag/hyperloopforum (click on "Enroll Now" to join) or submitted to Hyperloop@spacex.com.

2 GENERAL RULES

1. Any entity is welcome to enter the competition by September 15, 2015, and submit the Preliminary Design Briefing in October 2015. However, SpaceX, at its sole discretion, will select the teams that participate in the January 2016 Design Weekend. After submitting their Preliminary Design Briefing, teams will be notified within two weeks whether they have been chosen to participate in Design Weekend.
2. The team structure is flexible, with no minimum number of team members and no maximum number (within reason). If there is any question about eligibility, please email Hyperloop@spacex.com.
3. In addition to hosting the competition, SpaceX may enter a corporate team into the competition, but this team will not be eligible to win any prizes or awards.
4. Competition Weekend Prizes. The full prize package structure will be released later this year, but, at a minimum:
    - Cash prizes (amounts TBD) for the first, second, and third-place teams.
    - People's Choice Award, where the attendees vote for the coolest feature/design.
    - SpaceX, at its own discretion, may award prizes to teams (student and non-student) with any design features that SpaceX deems especially innovative with regard to design, safety, efficiency, and performance. SpaceX estimates it will award 5 to 10 of these innovation awards.
5. Design Weekend Prizes: See Section 5.
6. At SpaceX's discretion, Pod teams may be allowed to test their Pods on the test track before Competition Weekend.
7. Pods must meet the requirements provided in Section 6 and any future requirements released by SpaceX.
8. SpaceX, at its sole discretion, may allow or disallow entrants to access the test track.
9. **No human (or animal) shall ride in any Pod or other transportation device used within the test track during this competition or during any pre-competition access.**
10. The judging panel will be composed primarily of SpaceX engineers, Tesla Motors engineers, and university professors.
11. Determinations of the judging panel are final, and entrants may not protest results.
12. Competition Weekend is scheduled for June 2016, but the exact date will be determined at a later date.

3 PRELIMINARY DESIGN BRIEFING

This Preliminary Design Briefing package shall consist of a PowerPoint slide deck (in PDF format) of no more than 30 slides, which will include:

1. Description of team and updated list of all associated team members and advisors
2. Reiteration of whether team intends to build a Pod or just present a design at Design Weekend
3. Top-level design description for pod (or subsystem). At a minimum, this should include, where applicable:
    a. Estimated Pod dimensions
    b. Estimated Pod mass by subsystem
    c. Estimated Pod power consumption by subsystem
    d. Pod navigation mechanism
    e. Pod levitation mechanism (if any)
    f. Pod propulsion mechanism (if any)
    g. Pod braking mechanism
    h. Pod stability mechanisms (e.g. attitude and lateral motion)
4. List and description of any stored energy on the Pod (e.g. pressure vessels, batteries)
5. List of hazardous materials, if any
6. Top-level description of safety features

With their **Preliminary Design Briefing**, teams shall include a signed **Competitor Entry Agreement** that will be provided to teams who complete the Intent to Compete form on www.spacex.com/hyperloop by September 15, 2015.

Preliminary Design Briefings and signed Competitor Entry Agreement should be submitted to Hyperloop@spacex.com by 5pm PT October 22, 2015. In the subject line, write "Pod Competition Preliminary Briefing: TEAM NAME HERE". Teams may submit only one Preliminary Design Briefing copy; any copies received after the initial submission will not be accepted. Please check your documents carefully before submission. SpaceX will respond to your submission within 48 hours to verify receipt. If you do not receive verification within 48 hours, please re-contact SpaceX at the same email.

The purpose of this briefing is for SpaceX to "sanity check" the design and ensure the entrant is heading in a viable direction. Following the submission, there may be a down-select decision in order to properly manage the number of entrants. SpaceX will notify teams as to whether they have advanced within two weeks of Preliminary Design Briefing submission.

4 FINAL DESIGN PACKAGE

All entrants who have successfully advanced to the Final Design Package phase must upload a completed version of the Final Design Package on the Hyperloop Forum at http://tx.ag/hyperloopforum by 5pm PT on December 15, 2015. This is to facilitate uploading any large files. To upload, click on "Submit Final Design Package" in the left-hand navigation. Name your package as "Pod Competition Final Design package: TEAM NAME HERE". As with the Preliminary Design Briefing, teams may submit only one Final Design Package copy. Please check your documents carefully.

The Final Design Package must consist of:

1. Description of team and updated list of all associated team members and advisors
2. Reiteration of whether team wishes to build a Pod or just present a design at Design Weekend
3. If your team is unable to attend Design Weekend and wishes to present virtually, please indicate so, along with a detailed explanation
4. Design description for Pod (or subsystem). At a minimum, this should include:
    a. Pod top-level design summary
    b. Pod dimensions
    c. Pod mass by subsystem
    d. Pod payload capability
    e. Pod materials
    f. Pod power source and consumption
    g. Pod navigation mechanism
    h. Pod levitation mechanism
    i. Pod propulsion mechanism (if any)
    j. Pod braking mechanism
    k. Pod stability mechanisms (e.g. attitude and lateral motion)
    l. Pod aerodynamic coefficients
    m. Pod magnetic parameters (if applicable)
5. Predicted Pod thermal profile
6. Predicted Pod trajectory (speed versus distance)
7. Predicted vibration environments
8. Pod structural design cases: at a minimum, this shall include initial acceleration, nominal deceleration, and end-of-tube off-nominal crash
9. Pod production schedule
10. Pod cost breakdown
11. Sensor list and location map
12. Comments on scalability to an operational Hyperloop with respect to:
    a. System size (increased tube length, tube diameter, and Pod size)
    b. Cost (both production and maintenance)
    c. Estimated Pod mass and cost if built full-scale
    d. Maintenance (e.g. not requiring specialized alignment tools, hot-swappable subsystems)

Additionally, teams intending to build a Pod shall also submit:

1. Loading and unloading logistics plan (see Sections 7 and 9 for details)
    a. Full descriptions of all Functional Tests (see Sections 7 and 9)
    b. Full description of Ready-to-Launch checklist/state (e.g. Loop Computer in "Launch Mode" and sending telemetry, Pod hovering at 0.25 inches)
    c. Full description of Ready-to-Remove checklist/state (e.g. Wheels locked, Power Off)
    d. Description of how Pod is moved from Staging Area to Ingress Holding Area
    e. Description of how Pod is moved from Egress Holding Area to Exit Area
2. List and description of any stored energy on the Pod (i.e. pressure vessels, batteries)
3. List of any hazardous materials, if any
4. Preliminary bill of materials, with each line item categorized as "Commercial-Off-The-Shelf (COTS)" or "custom-built"
5. Description of safety features including:
    a. Mechanisms to mitigate a complete loss of Pod power
    b. Pod robustness to a tube breach resulting in rapid pressurization
    c. Fault tolerance of braking, levitation, and other subsystems
    d. Single point of failures within the Pod
    e. Recovery plan if Pod becomes immovable within tube
    f. Implementation of the Pod-Stop command
    g. A top-down hazard analysis OR a bottom-up Failure Mode and Effects Analysis (FMEA).
6. Component and system test program before the Pod arrives for Competition Weekend
7. Vacuum Compatibility Analysis

Additional fidelity on the individual data items will be made available to teams in October 2015.

5 DESIGN WEEKEND

Design Weekend will take place on January 15 (Friday) and January 16 (Saturday) at Texas A&M University, College Station. The Design Weekend logistics will be released by Texas A&M in September. Some general notes:

- Updates on Design Weekend details will be posted at: http://engineering.tamu.edu/hyperloop
- The goal of Design Weekend is for student teams to present their Pod designs, which, after receiving feedback, vetting, and approval to proceed, will be constructed for Competition Weekend. Non-student teams will be invited on a case-by-case basis to participate at SpaceX's discretion.
- Entrants are encouraged to attend in person. For those student teams who are unable to attend in person, we will likely have limited (i.e. 1 or 2) slots for virtual presentations by webcam. If your team is unable to attend Design Weekend and wishes to present virtually, please indicate this in your Final Design Package along with a detailed explanation.
- Entrants who are not interested in building a Pod may still present designs for a Pod, an individual subsystem, or an individual safety feature. As an example of an individual subsystem submission, a team could choose to optimize the Pod's aerodynamics or design the Pod's Service Propulsion System. The purpose of such submission is to receive design feedback and to participate in a fun educational event.
- Entrants will present before a judging panel, which will be composed primarily of SpaceX engineers, Tesla Motors engineers, and university professors.
- While teams are encouraged to begin finding sponsorships now, the primary rewards for Design Weekend participation are access to corporate sponsorships. Select companies invited by SpaceX will be able to use Design Weekend as a platform for selecting teams to sponsor. At their discretion, such companies may contribute funds toward the construction of their sponsored team's Competition Weekend Pod. Entrants who are selected for sponsorship may elect not to be sponsored or receive funds, at their discretion.
- SpaceX, at its own discretion, may award multiple innovation awards (each of which includes a small cash prize) to teams with any design features that SpaceX feels are innovative with regard to safety, efficiency, and performance.

6 POD REQUIREMENTS

The Pod requirements are intentionally broad in order to encourage diversity of design. Feel free to post any questions about Pod requirements to the Hyperloop Forum at http://tx.ag/hyperloopforum or email them to Hyperloop@spacex.com.

1. Mass: Less than 11,000 lbm (5,000 kg)
2. Dimensions: Pods shall be less than 14 feet in length. Pods can be any shape with the main requirement being that they fit within the tube. The tube's exact cross-section will be released in September. To provide initial estimates, Pods shall be less than 3.5 feet in width at the base, less than 4.5 feet in maximum width, and less than 3.75 feet in height. When the final tube specifications are released in September, it is possible that these maximum values will change, but they won't decrease.
3. Service Propulsion System: The Pod shall be moveable at low speeds when not in operation, which may be accomplished by physically pushing it (wheels), physically lifting it (even with a dolly), or remotely controlling it. While pushing and lifting are reasonable for Pod loading, it is highly recommended that the remote control be implemented for unloading. Without a remote system, it will be more difficult to guarantee that the Pod reaches the Egress Holding Area in the event it becomes immovable in the Hyperloop tube.
4. Levitation System(s): The mechanism(s) for levitation is up to the entrant and is not actually required. Wheeled vehicles (e.g. an "electric car in a vacuum") can compete, but are unlikely to win prizes.
5. Operational Propulsion System: This is not required (or suggested), as the SpaceX test track will be providing initial linear impulse. However, teams are not prohibited from having a different primary system (e.g. an electric car) or an auxiliary system (to maintain speed during coast).
6. Operational Propulsion Interface: In order to accelerate the Pods, SpaceX will provide a mechanical interface, which will then be accelerated to operational speed. If the Pod chooses to utilize the interface, the Pod will remain attached to the Operational Propulsion Interface during the entire acceleration phase.
7. Braking system: Each Pod must be able to reduce to zero speed in a controlled fashion (i.e. brake). Braking can be done in any reasonable manner, including, but not limited to, brake tabs, wheels, system drag, or onboard propulsion. SpaceX may choose to provide a permanent magnet surface near the end of the main tube to allow for non-contact electromagnetic braking. Braking system actuation must be demonstrated, if feasible, in one of the pre-launch Functional Tests (see Section 7). The braking system, where feasible, shall be at least 1-fault tolerant.
8. Communications: Within the tube, SpaceX will provide a secure 2.4 GHz WiFi network for all command, data and video communications. Ability to send and receive data and commands (through a GUI created by the entrants) must be demonstrated during Functional Tests.
9. Telemetry: At a minimum, the telemetry stream must include the following data (at a minimum speed of 1 hz):
    a. Position within tube (X, Y, and Z)
    b. Velocity within tube (X, Y, and Z)

c. Acceleration within tube (X, Y, and Z)
d. Vehicle attitude (roll, pitch, and yaw)
e. Pod pressure (only applicable if Pod has any pressurized sections)
f. Temperature from at least two points on the Pod
g. Power consumption

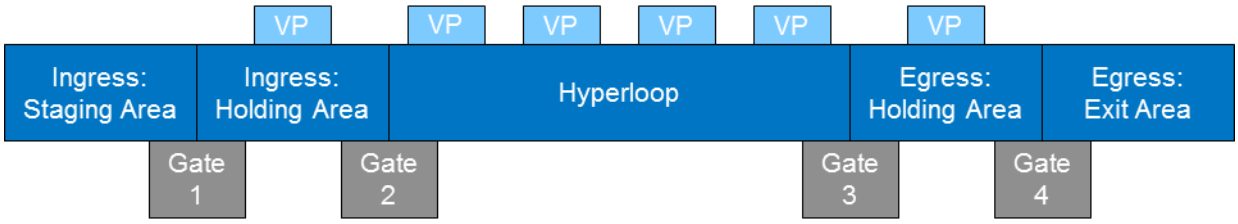
10. Vibration Environments: SpaceX will provide a self-contained flight data recorder to monitor dynamic environments. After the flight, SpaceX engineers will use this data as part of the judging criteria. Pods must accommodate the unit, which will weigh less than one pound. The interface will be released in late 2015.
11. Pod-Stop Command: Through a remote command, Pods must be able to be commanded to stop safely. The physical mechanism for stopping can, but does not have to be, the same as the Pod's standard braking mechanism.

7 POD LOADING

The Pod loading sequence is as follows. Please note that, since every Pod will have unique features, all teams are required to submit a Pod loading and unloading plan as part of their Final Design Package:

1. Before loading, the Team Captain will give a 15-minute Safety and Logistics briefing to the Judging Panel and Hyperloop Test Director (a SpaceX or Tesla employee), which includes a description of their Pod Design, Pod-handling safety, and the loading/unloading process. The Hyperloop Test Director will also lead a safety and technical inspection of the physical Pod. The loading cannot proceed until the Hyperloop Test Director approves.
2. Pod will be transported via road to the Hyperloop Staging Area. Pods will be lifted, via a SpaceX-provided crane if necessary, onto the Staging Area, an open-air flat surface 20 feet in length.
3. On the Staging Area platform, Pods will perform Functional Test A, which will include a demonstration of power-up.
4. When Functional Test A is complete, Gate 1 will open and the Pod will be moved into the Ingress Holding Area using the Pod's Service Propulsion. The Holding Area is an enclosed airlock 20 feet in length.
5. On the Holding Area platform, the Pod will be physically connected to the Mechanical Propulsion Interface. This is not applicable if the Pod is not using the Hyperloop's Operational Propulsion System (e.g. an electric car). Once connected, Functional Test B will be performed, which may include vehicle hovering.
6. Gate 1 will then be closed and Functional Test C will be performed. This includes the demonstration of a continuous communications link.
7. The Holding Area will be depressurized to operating pressure.
8. At operating pressure, Functional Test D will be performed.

Functional Diagram (not to scale) of the Test Track. VP refers to Vacuum Pumps.



Summary of Pre-Launch Functional Tests

Test ID	Location	Suggested Duration (min)	Suggested Items
A	Staging Area	5	Power-on, 2-way communications
B	Holding Area (Gate 1 open; Gate 2 closed)	5	Levitation
C	Holding Area (Gate 1 & 2 closed)	2	Communications
D	Holding Area (vacuum)	5	Levitation

8 POD LAUNCH

1. Once the Pod has passed Functional Test D, Gate 2 will be opened.
2. The Pod will then go through its Pre-Launch procedures, which places it in "Ready-to-Launch" mode.
3. The entrant will then signal the Hyperloop Test Director that it is Ready-to-Launch.
4. The Hyperloop Test Director will activate the Operational Propulsion System.
    a. If the Pod is not using the Operational Propulsion System, Step 4 will be skipped.
5. Launch!
6. Upon launch, the Pod will undergo three phases of "flight":
    a. Acceleration Phase: The Pod is accelerated through its mechanical interface to the Operational Propulsion Interface. Once the Pod has been accelerated to speed, the Operational Propulsion Interface will stop, freeing the Pod.
    b. Coast Phase: The Pod coasts down the main Hyperloop section.
    c. Deceleration Phase: The Pod brakes itself, coming to rest in the Egress Holding Area.

9 POD UNLOADING

1. The Pod is responsible for reaching the Egress Holding Area, an enclosed airlock that is a minimum of 40 feet in length. SpaceX will likely provide a backup system to ensure the Pod reaches the Egress Holding Area, (i.e. a remote pull-cart), but the teams should not rely upon this system.
2. Once in the Egress Holding Area, Gate 3 will be closed.
3. The Egress Holding Area will then be pressurized.
4. Once at pressure, the Pod will perform a safety test before approaching Gate 4, known as Functional Test E, in order to verify that it is safe to proceed. If the Pod requires manual movement from Egress Holding Area to Exit Area, the test must also verify that the Pod is safe to approach.
5. When the Hyperloop Test Director deems the operation as safe, Gate 4 will be opened.
6. The Pod will then be moved into the Exit Area, an open-air flat surface 20 feet in length.
7. The Pod will be placed into a safe powered-down "Ready-to-Remove" state.
8. The Pod will then be removed from the Exit Area via crane or other method.

10 TOP-LEVEL COMPETITION WEEKEND JUDGING CRITERIA

Category 1: Final Design and Construction	**Points**
Overall quality of construction	100
Overall cost of materials (normalized per payload mass)	100
Levitation system	75
Braking system	75
Ability to economically scale	50
Power consumption (normalized per payload mass)	50
Payload capability (as % of overall mass)	50
Category 1 Total	**500**
Category 2: Safety and Reliability	
Structural margins of safety and design cases	100
Pod-Stop command	100
Safety in operations	50
Fault tolerance of braking system	50
Fault tolerance of levitation systems	50
Fault tolerance of other systems	50
Loss of power contingency	50
Tube breach contingency	50
Category 2 Total	**500**
Category 3: Performance in Operations	
Efficiency of transport from Staging Area to Ingress Holding Area	100
Efficiency of Functional Tests	100
Efficiency of connection to the Operational Propulsion Interface	100
Efficiency of transport from Egress Holding Area to Exit Area	100
Pod is removed from the tube without requiring tube pressurization	100
Category 3 Total	**500**
Category 4: Performance in Flight	
Total distance Pod travels	200
Minimization of system drag	200
Functionality of Pod braking/deceleration system	200
Tightness of lateral control around Hyperloop center-line	100
Attitude control system	100
Comfort of ride (per measured vibration environment)	100
Reliability of data stream and DAQ software	100
Category 4 Total	**1000**
Total Points Possible	**2500**

Note: Objective figures of merit for categories will be released with tube specifications.