SpaceX Hyperloop Safety and Testing Checklist

Revision 1.0

December 28, 2016

Contents

Upon Arrival

1. **General Safety Briefing**
    a. Shortly after arrival and before any work is performed on the Pod, each team will be given a General Safety Briefing by the SpaceX Environment, Health and Safety (EHS) team.

2. **Pod Unpacking**
    a. Teams' shipping crates will be stored in their respective Headquarters, which is a 10'x10' tent with power in the Competition Testing Lot (see map on last page).
    b. Teams may receive approval to unpack, but not to perform any hazardous operations, in two manners:
        i. If a team has received a pre-approval from SpaceX Advisors before arrival, it may unpack its Pod following the General Safety Briefing.
        ii. If a team has not received said approval, it will need to receive approval at its onsite team-specific Safety Briefing
    c. This section strictly refers to "basic non-hazardous unpacking"; it does not apply to powering on the vehicle, unpacking magnets, pressurizing systems, etc.
    d. No hazardous operations may be performed without SpaceX advisors present and without following approved procedures.

3. **Other Logistics**
    a. There is a Hyperloop Wi-Fi network in the Competition Testing Lot. **Each team is permitted one user on the Hyperloop Wi-Fi network.**
    b. Multiple Network Access Panels (NAP's) will be circulating for fit checks
    c. Restrooms are available in the Competition Testing Lot
    d. Water will be provided, and food trucks will be onsite each day
    e. With the exception of organized tours approved by SpaceX, the only SpaceX property students/non-SpaceX-employees may access is the Competition Testing Lot. Students/non-SpaceX-employees will not be permitted to enter any SpaceX facility.
    f. Each team member will receive a Hyperloop Team Member Badge. This badge is required to gain access to the Competition Testing Lot for the remainder of the week. Access will not be granted without a badge ("No badge no entry"). Team Members should take care to not lose badges.
    g. With regards to Identification:
        i. U.S. Citizen team members must bring a valid Driver's License, Passport, or State ID for registration.
        ii. U.S. Permanent Resident team members must bring their valid Permanent Resident Card (green card)
        iii. International team members must bring their valid Passports.
        iv. For all IDs, copies will not be accepted.
        v. A US Visa is not a valid form of ID.
    h. During Testing Week (1/22 – 1/26), teams will not be allowed to take photos or video while on SpaceX property, which includes the External Subtrack and the Vacuum Chamber. If teams need to take a photo of their Pod for testing purposes, SpaceX personnel can take said pictures with a SpaceX camera/phone and email to teams.
    i. Competition Week (1/27 – 1/29) photography policy will be released at a later time
    j. No parking will be available in the Competition Testing Lot due to space constraints; however, SpaceX is investigating other nearby parking alternatives and will communicate with teams if other parking options become available.

Team-Specific Safety Briefing

Teams will participate in a safety dialog with their SpaceX Advisors and members of the EHS team. The numbered items below are the items that will be covered in said Safety Briefing.

It is unlikely that teams will cover all of the topics below in their first briefing. Instead, getting through certain portions will allow teams to proceed with incremental testing (see Testing section below). However, all portions must be completed to receive approval to conduct test activities in the Hyperloop.

If a team has a design element which SpaceX Advisors do not believe is safe, the team and its SpaceX Advisors will agree on a go-forward plan in order to resolve that issue. As an example, if a battery is improperly fused, a go-forward plan could be "Go into the Vacuum Test with the battery off the bus; in the meantime, purchase fuses and prepare to install and test them." If a design element has been flagged as unsafe by SpaceX Advisors and a team is unable to execute a go-forward plan to remediate the issue(s), the team will not be permitted to proceed with the applicable testing.

1. **Summary of Top-Level Pod Information:**
    a. Pod mass
    b. Pod length
    c. Pod levitation type (e.g. stationary magnets, rotating magnets wheels, air bearings, etc.)
    d. Pod primary/secondary braking types (e.g. magnets, friction)
    e. List of hazardous systems/materials on Pod (e.g. battery, magnets, high-pressure bottles)
    f. Pod method(s) for acceleration (e.g. SpaceX Pusher)
    g. Maximum speed at which Pod can maintain control while levitating
    h. Maximum speed at which Pod can maintain control while not levitating (e.g. on wheels; if no wheels are on Pod, the answer is zero mph)
    i. Maximum acceleration at which Pod has been structurally designed
    j. Maximum acceleration for which Pod can maintain control
    k. Supporting documentation (teams should have this available upon request)
        i. Safety Briefing previously submitted to SpaceX
        ii. All Procedures: Procedures should be provided for all aspects of testing including, but not limited to:
            1. Pod Loading and Unloading
            2. Pod Intra-SpaceX Transport
            3. Pod Power-On
            4. Pod Magnet Installation
            5. Pod Pressure Vessel Pressurization
            6. Contingency (e.g. recovery in case of a failure, battery fire)
        iii. Electrical block diagram for all components, showing all connectors and how any ground equipment interfaces to Pod.
        iv. Power and grounding schematic showing voltages present and ground tie methods between chassis and power return
        v. Fluid schematics
        vi. List of any equipment the Teams are bringing on site

2. Initial Pod Operations

a. Current Pod state at time of Safety Briefing
    i. How many "discrete pieces" is the Pod currently in?
        1. Example response would be "Three: Pod structure is in one crate, the batteries are in a second crate, and the magnets are in a third crate"
    ii. Are there any systems currently pressurized?
    iii. If compressed air is needed, is it onsite?
b. If a team has not received an Unpacking Pre-approval, determine the Pod state that, following the Safety Briefing, the team is approved to proceed to. For example, "Team may unpack and assemble Pod, but may not install battery or magnets."
c. Make sure all parties are clear on what the next steps will be once the Pod is unpacked (e.g. power on vehicle, mechanical fit check, etc.)

3. Pod Transport

a. To perform tests, the Pod will be transported to/from various testing facilities.
b. How is Pod physically moved (e.g. dolly, forklift, hand-carried, etc.)?
c. How will Pod be physically lifted into the Vacuum Chamber and Hyperloop Staging Area?
d. How will Pod be physically loaded onto the External Subtrack?
e. Are all lifting/transport fixtures currently installed and onsite?
    i. This is important as, if a team's testing time arrives and their Pod is not ready for immediate transport, the slot will be forfeited to the next team in line.
f. During transport, is the vehicle powered on?
g. During transport, are any tanks pressurized?
h. What is the Clear Zone during Pod Transport?
i. Provide Pod Transport Procedure if requested by SpaceX Advisor
j. SpaceX Advisor must approve Pod Transport Procedure before Pod can be transported to a testing facility.

4. **Hazardous Operations - Magnets**
    a. Provide Pod's maximum magnetic field strength
        i. For reference, 0.5 milli-Tesla or 5 Gauss is considered safe for pacemakers
    b. Provide Safe Distance/Clear Zone around Pod (during installation and transport) due to magnetic field
    c. Identify which team members are qualified to perform the magnet installation
    d. Step through Magnet Handling procedures.
    e. Verify that all team members who will be handling magnets are not wearing any ferro-magnetic materials
    f. If requested, provide a plot of magnetic fields / fringe lines for the entire vehicle when active (see example below).
    g. If rotating magnetic arrays are employed that allow stationary hovering, verify duration of levitation which would result in damage to the aluminum plate
    h. SpaceX Advisor Approval must be given for teams to install magnets

MRI suite

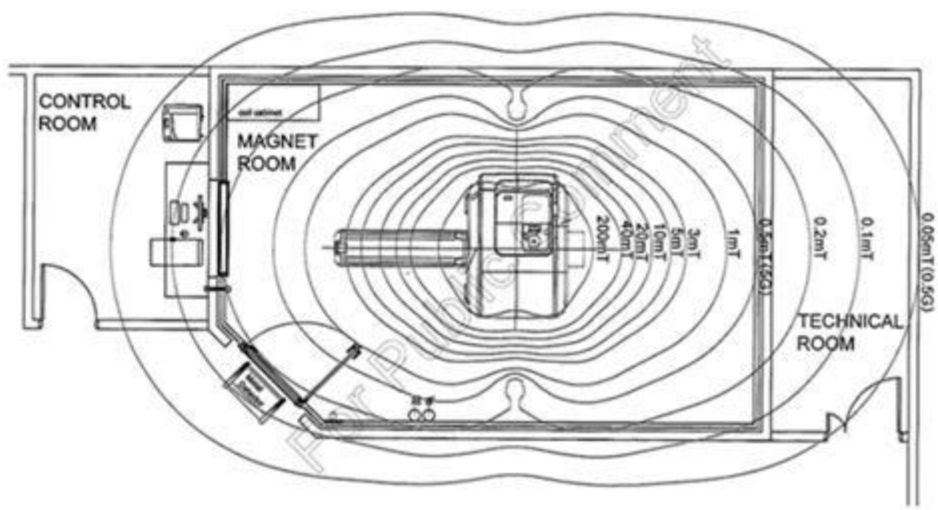


Figure A.1. An over view of magnetic field fringe line

5. **Hazardous Operations - Pressurized Systems**
   a. Identify the number of tanks
   b. For each tank, identify:
      i. Tank volume
      ii. Tank pressurant (e.g. compressed air, nitrogen, etc.)
      iii. Tank pressure during nominal operations
      iv. Tank safety ratings, including MAWP, MEOP and BURST
      v. Pressure relief paths (e.g. though the air bearings themselves, through a separate relief valve, etc.)
   c. Provide Quantity Distance Calculation, TNT equivalence, and resultant Clear Zone at maximum operating pressure
   d. Provide evidence that each pressure vessel has been proof-tested – this could be a video or photos that show the test and pressure gages.
      i. **Pressure systems must be fully proofed before arrival (no proof testing may be done onsite).**
   e. Provide evidence that all components have been torqued to the appropriate value and include in the team's procedures how this will be verified while onsite
   f. Provide verification, if any, that no overloads occurred during transport (e.g. accelerometer data, temperature data, etc.)
   g. Provide full procedures for:
      i. Leak checks for any connections that had to be broken for transport.
      ii. Pressurizing the tanks
   h. What state is the pressure system in if vehicle power is lost?
   i. Provide all methods for venting the pressure vessels:
      i. Nominal operations
      ii. Loss of power
      iii. Loss of communications
   j. For Pods that use air pressure for levitation: If power is lost, what state does the levitation system enter? An example response is: "Air supply is isolated and the Pod descends."

6. Hazardous Operations - Batteries

a. Identify the number of separate battery packs (not cells, but integrated packs).
b. For each battery, identify
    i. Type and brand of cells
    ii. Off-the-shelf or made-in-house
    iii. Number of cells in parallel and in series
    iv. Total energy stored (in kW-hr)
    v. Pack voltage
    vi. Maximum rated current
    vii. Which hardware is powered from each battery
        1. Example: some Pods have small batteries to power their flight computer and large batteries to power rotating magnetic arrays
    viii. Pods' nominal and peak operating current and power
c. Based on current draws, demonstrate that proper fuses have been implemented
d. Provide the battery's expected maximum temperature (based on its current profile) and its operating temperature range (likely from data sheet).
    i. Provide the number of battery temperature sensors, and where they are placed
e. Provide test results, data, and/or rationale for how batteries and power electronics will operate at vacuum pressures
    i. If data provided to SpaceX Advisors is insufficient, battery-only vacuum tests may be needed (both passively and/or under load).
    ii. Examples:
        1. Pouch cells can bulge and/or break when exposed to vacuum
        2. Certain electrolytic capacitors can burst when exposed to vacuum
f. Provide Power-On procedure for vehicle, including, but not limited to:
    i. How are the batteries brought onto the bus? For example:
        1. Is there a mechanical on-off switch? Is it susceptible to vibration?
        2. Is there a remote command?
    ii. What is the nominal current draw when first brought online?
    iii. If the current draw is non-nominal, what actions will be taken?
    iv. Which hardware is initially powered when each battery is brought online?
    v. Will there be any motion when Pod is initially powered?
g. What mechanisms exist for taking the battery offline (e.g. mechanical switch, disconnecting a connector, remote command, etc.)?
    i. If the only mechanism is manually disconnecting a connector, this could be hazardous.
h. Provide Power-Off procedures for vehicle (likely overlaps with item above)
i. This section provides the basis for SpaceX Advisors to give the approval for teams to:
    i. Install batteries onto their Pod
    ii. Power on Pod at Team Headquarters

7. Software and Navigation Systems

a. Provide a software state machine diagram which lists and connects all software states, along with how transitions between these states occur.
b. For each state transition, list the criteria used (e.g. "Acceleration > 0.1 g") and the mechanism for determining the transition (e.g. "Accelerometer")
c. The quantity and location of all sensors used for mode transitions (e.g. "Three accelerometers co-located in the Flight Computer chassis")
d. Discuss accuracies of each sensor. For example, if the Pod is integrating accelerometers, the drift should be quantified as position error over time and velocity error over time
    i. A "Parking Lot Navigation Test" may be required to demonstrate accuracies before testing in the Hyperloop (see Testing section below).
e. Discuss fault detection in the sensors. For example, if a team is using three accelerometers, what does the software do when an accelerometer fails and starts outputting zeroes?
f. If optical tape is being used as a mode transition, provide rationale that the Pod can properly detect the tape, especially at speed
g. Identify each state where the brakes nominally actuate
h. After each run, how does the Pod know that it has come to rest?
i. Provide list of Software State Diagram tests to verify that one cannot prematurely enter these states. These tests will be run at SpaceX. **This test list is extremely critical.**
    i. State Diagram Transition Tests are mandatory before a testing on the External Subtrack or in the Hyperloop (see Testing section below).
j. SpaceX is most concerned about:
    i. Mechanisms for inhibiting Pod braking during the acceleration period
    ii. The software state if loss of communications occurs
    iii. Criteria for Pod to initiate braking at the end of the run
k. During the coast phase, are there any abort criteria (e.g. battery temperature too high, battery state of charge too low, air pressure too low, etc.)?
    i. Provide list of all abort criteria
    ii. Provide description of abort state (e.g. brakes, battery, etc.)
    iii. If no abort criteria are in place, please explain rationale
l. *For teams with Pods that can levitate in place (e.g. air-bearings, rotating magnets, etc.)*
    i. Demonstrate the software commands used to initiate hovering
    ii. Demonstrate the software commands used to terminate hovering (e.g. if the Pod is executing a stationary hover test, how does the test end?)
    iii. In which states is the Pod levitating?
    iv. If communications to the Pod is lost, in which of these states does the Pod autonomously terminate hovering?
m. SpaceX Advisors must approve this section, **along with a list of all Navigation Tests and State Diagram Transition Tests to be run**, in order for the Pod to partake in any motion test involving the SpaceX Pusher

8. **Braking System(s)**
    a. Provide description of primary braking system:
        i. Mechanism for braking (e.g. magnet, friction, etc.)
        ii. State of brakes when engaged and power is lost
        iii. State of brakes when unengaged and power is lost
        iv. Description of mechanical failures which would lead to inadvertent brake engagement
        v. List of hardware and software inhibits to inadvertent
    b. Provide description of secondary braking system: same fields as for primary system
    c. If any contact is made with the Hyperloop rail, explain how braking will not result in damage to the Hyperloop
    d. Verify that no friction braking is utilized with the aluminum plate
    e. State of vehicle needed in order to functionally test/actuate brakes on bench (e.g. powered on, tanks pressurized, etc.)

9. **Pod Unloading**
    a. Once a motion test is complete (on the External Subtrack or in the Hyperloop), what state is the vehicle in (what is powered, what is pressurized, etc.)?
    b. What state must the Pod be in to allow for a person to safely approach it (e.g. pressure vessels are vented, main batteries off bus, brakes disengaged, etc.)?
    c. For a Hyperloop test, how is the Pod removed from the Hyperloop, given that it will end its test 50 - 100 feet from the egress in a nominal run and possibly hundreds of feet for an off-nominal run? This has previously been referred to as the Pod's "Service Propulsion System." Example answers:
        i. A remote command allows the vehicle to roll forward at a slow speed
        ii. A person must step into the tube and manually push it
    d. SpaceX Advisors must approve the Pod Unloading Plan in order for the Pod to be placed in the Hyperloop, including for the Open-Air Hyperloop Test

10. **Pod Health Check**
    a. Before Pods are permitted to operate in the Hyperloop, teams will need to demonstrate that their Pods are in a healthy condition
    b. To do this, teams need to provide a checklist of variables and their nominal ranges. Examples include battery temperatures, battery voltages, battery states of charge, pressure vessel pressures, etc.
    c. Besides the actual variable list, teams must also demonstrate how they verify said ranges during the health check.
        i. One common method is to have several numerical boxes which turn green when in range and red when out of range. See picture below.
        ii. It is important for the Health Check to be performed quickly (i.e. one minute), which is only possible with an intuitive GUI
    d. Health Check list must be approved by SpaceX Advisors prior to a Hyperloop run

Sample Portion of Pod Health Display

	Min	Actual	Max
Battery Voltage 1	20	28	36
Battery Voltage 2	20	18	36

Pod Testing

Any testing that requires a SpaceX Facility (Vacuum Chamber, External Subtrack, and Hyperloop), must be scheduled with the SpaceX Master Scheduler while onsite. All other tests can be scheduled directly with SpaceX Advisors.

1. **Structural Inspection**
    a. Entry criteria
        i. Approval from SpaceX Advisors to unpack and assemble Pod
        ii. Approval from SpaceX Advisors to integrate magnets and batteries (if applicable)
        iii. Vehicle power is off (i.e. battery is offline)
    b. What will be inspected?
        i. Basic visual inspection of Pod
        ii. Primary structural components
            1. Demonstrate fasteners are torqued to appropriate values
        iii. Pressurized systems
            1. Demonstrate that all fittings are torqued to appropriate values
            2. Demonstrate no damage to critical components during transport
        iv. Demonstrate all connectors and harnesses are properly secured
    c. Exit criteria: Approval by SpaceX Advisors

2. **Functional Test**
    a. Entry criteria
        i. Successfully passing Structural Inspection
        ii. Approval from SpaceX Advisors to power on Pod
    b. What should be tested?
        i. Pod is powered on and nominal current draw is observed
        ii. Demonstrate proper flight computer state
        iii. Sensors are properly telemetering data, including, but not limited to:
            1. Battery temperature sensors
            2. Battery state of charge
            3. Battery voltage
            4. Navigation sensors
        iv. Any actuations that are safe to test on the bench:
            1. Actuations of primary and secondary brakes
            2. Valve state changes
            3. Relay state changes
            4. Rotation of magnetic arrays, if applicable
        v. Execute a full Pod Health Check, where SpaceX Advisors can see that all variables on the Pod Health Check list are updating and within range.
        vi. If possible, battery should be discharged at maximum load
        vii. Relevant pressurization and pressure relief testing, as determined with the SpaceX Advisors
        viii. If NAP is not available, verify manual commanding through Wi-Fi or Ethernet, including safety-critical commands such as "Emergency Stop" or "Battery off Bus"
        ix. NAP Network Testing (can be done at a separate time if NAP is not available)
            1. When teams are provided a NAP, it will be plug-and-play. Connecting it to the Ethernet port on the Pod will place the Pod automatically on the Hyperloop network.
            2. Confirm that all IP addresses are within the specified range of 192.168.0.5-254.
            3. Disable all network interfaces on the laptop which will not be used for communicating with the Hyperloop Network.
            4. Confirm that the power interface to the nap provides 9-36VDC, and is able to source 20W. Confirm the polarity of the power interface matches the NAP specification.
            5. Confirm that the team's laptop can communicate over the specified IP address region to the Pod.
            6. Verify remote commanding through NAP, including safety-critical commands such as "Emergency Stop" or "Battery Off Bus"
            7. Verify Pod telemetry is being received, including the SpaceX-required Pod Monitoring Telemetry. **Note that the Pod Monitoring Telemetry, plus the additional telemetry required in the Entry Criteria, must be functional in order to proceed with a powered-on Vacuum Test.**
    c. Exit criteria:
        i. All systems described above are safe and nominal
        ii. Approval by SpaceX Advisors

3. Mechanical Fit Check

a. This can be done either:
    i. Coarsely in Team Headquarters with SpaceX-provided pieces of aluminum rail and plate (does not have to be scheduled).
    ii. More accurately on the External Subtrack (must be scheduled)

b. Entry Criteria
    i. Approval from SpaceX Advisors.
    ii. *If Pod is in any state beyond inert (i.e. powered or pressurized)*: Successfully passing Functional Test
    iii. *For Pods who wish to levitate in place*: Successfully passing of full Functional Test
    iv. *If the External Subtrack is used*: Approval by SpaceX Advisors of Pod Transport Procedure

c. What is tested?
    i. The operation of loading Pod onto the plate and rail
    ii. Proper fit when all brakes are disengaged
    iii. Proper fit when primary brakes are engaged
    iv. Proper fit when secondary brakes are engaged
    v. Proper fit when all brakes are engaged
    vi. The operation of unloading Pod onto the aluminum plate and rail

d. Exit criteria: The six criteria above all test nominally, as agreed to by the Team and by the SpaceX Advisors

4. **Vacuum Test**
    a. This refers to the full Vacuum Test, where the Pod is fully functional in the Vacuum Chamber (as opposed to a sub-scale test, such as a battery-only test)
    b. Entry criteria
        i. Approval by SpaceX Advisors of Pod Transport Procedure
        ii. Approval by SpaceX Advisors of Pod Unloading Plan
        iii. Successfully passing Functional Test
            1. If portions of the Functional Test are passed, a limited Vacuum Test may be performed. Examples:
                a. If a team passes all but the Power section, a power-off Vacuum Test could be performed.
                b. If a team does not pass the Pressurized Systems portion, a power-on Vacuum Test can be performed
                c. Pod Health Check list and Pod Monitoring Telemetry must be functional for all powered-on Vacuum Tests
    c. Test Logistics
        i. When a team is called into Vacuum Test, Pod must be ready for transport
        ii. Pod will be transported to Vacuum Chamber using Pod Transport Procedure
        iii. NAP will be given to Pod either before transport or at Vacuum Chamber
        iv. Pod will be placed into Vacuum Chamber and door will be closed.
        v. Vehicle telemetry connectivity will checked before pumpdown begins
        vi. Pod Health Check will be performed before pumpdown begins
        vii. Vacuum Chamber will be depressurized to 10 torr in approximately 7 minutes, held for approximately 20 minutes, and then re-pressurized in approximately 5 minutes.
        viii. Pod Health Check will be performed before door is opened
        ix. If the Pod is deemed safe, door is opened and Pod is removed from Vacuum Chamber using its Pod Unloading procedures
    d. What should be tested?
        i. Pod systems should all be monitored and checked while at vacuum:
            1. This includes all moving parts: brake systems, linear actuators, and, if possible, the levitation system.
        ii. If possible, battery should be discharged at maximum load
        iii. Pod should enter its software state diagram if possible (even if it stays in the "Waiting for Pusher" mode for 20 minutes, this is a useful demonstration).
    e. Exit Criteria:
        i. Pod systems all function nominally, temperature changes are all within an expected range, Pod telemetry is consistent, and actuations are nominal.
        ii. Visual inspection of Pod reveals no damage, including electronics damage (e.g. bulging of pouch cells, exploded capacitors, etc.)

5. Navigation Test

a. This test can take many forms, and thus the entry criteria is left general.
b. This test can be combined with the External Subtrack Test or Open-Air Hyperloop Test. However, since those tests need to be scheduled and time will be limited, it is likely more efficient to perform the Navigation Test in the Competition Testing Lot, where it can be performed at any time.
c. Entry criteria
    i. Approval by SpaceX Advisors of Pod Transport Procedure
    ii. Approval of SpaceX Advisors of all Navigation Tests to be run
    iii. Successfully passing {relevant portions} of the Functional Test
d. Test Logistics
    i. Test takes place in open space in Competition Testing Lot
    ii. Pod is placed in a safe and mobile state (i.e. on its own wheels or a supporting platform with wheels) and initiated to the same Software State as in an actual run.
    iii. Team shows telemetry values of position and velocity via its GUI
    iv. Pod is left stationary for five minutes, and the navigation drift, if any, is observed.
    v. Pod is manually moved a distance of 200 feet and brought to a rest
    vi. Team shows resultant telemetry values of position and velocity via its GUI
    vii. Test variations can be repeated as necessary, including:
        1. Repeating the test with a failed (e.g. unplugged) navigation sensor and ensuring the fault detection software works properly
        2. Using the optical tape fixture to see sensitivity of Pod's sensor
    viii. Exit Criteria
        1. Approval from SpaceX Advisors

6. **State Diagram Transition Test**
   a. This test is similar to the Navigation Test, except its primary goal is to verify that the Software will not initiate braking while attached to the Pusher. In most cases, this comes down to verifying these two critical items:
      i. The clock cannot start running before pushing has been initiated
      ii. A time threshold is properly implemented that cannot be over-ridden by navigation sensors
   b. Entry criteria
      i. Approval by SpaceX Advisors of Pod Transport Procedure
      ii. Approval of SpaceX Advisors of all State Diagram Transition Tests to be run
      iii. Successfully passing {relevant portions, as determined by SpaceX Advisors} of the Functional Test
   c. Test Logistics
      i. Test takes place in open space in Competition Area Lot
      ii. Test will likely be repeated several times due to the multiple mode transitions; thus, it is wise for each team to be able to efficiently reset its State Diagrams
      iii. Team provides list of Software State tests that was approved in the Safety Briefing. This list will again be evaluated before testing begins.
      iv. Pod is placed in a safe and mobile state (i.e. on its own wheels or a supporting platform with wheels) and initiated to the same Software State as in an actual run.
      v. Team shows telemetry values of time and Software State via its GUI
      vi. Pod is manually moved in order to trigger the proper state transitions.
      vii. Example Test 1 ("Don't Brake Too Soon After Being Released")
         1. Accelerate Pod to simulate being pushed
         2. Stop Pod and then immediately move Pod in a way that would trigger braking
         3. Verify braking does not occur because time threshold has not been met
      viii. Example Test 2 ("Brake If Navigation System Has Failed")
         1. Accelerate Pod to simulate being pushed
         2. Stop Pod to simulate coast
         3. Hold Pod still and verify that brakes eventually actuate
      ix. Example Test 3 (Don't Start Clock Too Quickly)
         1. Place Pod in Pre-flight Mode
         2. Mildly shake the Pod
         3. Verify the clock does not start ticking
      x. Example Test 4 (Terminate Hovering during Stationary Test)
         1. Relevant only to Pods which levitate before acceleration
         2. Command Pod to hover
         3. Cut communications
         4. Verify the Pod descends
   d. Exit Criteria
      i. Software behavior matches pre-approved State Diagrams in all cases
      ii. SpaceX Advisors and Team all agree that premature braking is non-credible

7. External Subtrack Test

a. This test takes place on the 150-foot External Subtrack in the Competition Area Lot.

b. Entry Criteria

   i. Approval by SpaceX Advisors of Pod Transport Procedure

   ii. Successfully passing {relevant portions} of the Functional Test

   iii. Successful completion of State Diagram Transition Test

   iv. For teams who plan on stationary levitation:

      1. Previous demonstration of stationary levitation (either in Vacuum Test or during Mechanical Fit Check)

      2. Verified duration of levitation which would result in aluminum plate damage

   v. Approval of Pod Health Check list (a custom sub-set can be approved for this test if needed; the full list must be operational for future Hyperloop tests)

c. Pre-Test Discussions

   i. Communication of pre-approved Safe Distances and Clear Zones

   ii. Communication on whether Pod will be levitating for this test, when levitation will begin (e.g. before Pusher begins to accelerate or afterwards), and at what speed levitation will occur

d. Test Logistics

   i. Implementation of Clear Zone

   ii. Verification that Overrun Attenuator is in place

   iii. NAP will be given to Pod either before transport or at External Subtrack

   iv. Using Pod Transport Procedure, Pod shall be transported onto the External Subtrack. It will likely be installed at the far end of the subtrack and then pushed backwards to the front, where the SpaceX Pusher is stationed

   v. The Pusher and Pod shall be connected, and all parties will do a visual inspection to make sure there is no interference, both in the ground and hovering configurations

   vi. SpaceX shall initialize the Pusher, which includes the customized speed profile:

      1. Initial profiles will be slow and short (e.g. 3 miles per hour for 3 seconds)

      2. Speeds/times will be ramped up accordingly

      3. Maximum speed is 25 miles per hour

   vii. Team shall initialize its Pod into the pre-tested Pre-launch State and, if applicable, verify that the time variable has initialized properly

   viii. Once both SpaceX and Team have verbally said “Go,” SpaceX will initiate the Pusher

   ix. Once the run is over, Pod enters or is placed into a pre-approved safe state and performs the Pod Health Check

   x. Following the test, both SpaceX and Team will review data, and then re-initialize the test and repeat

e. Exit Criteria

   i. Pod smoothly separates from Pusher

   ii. Pod properly transitions through its state diagram and does not brake while attached to the Pusher

   iii. Pod translates smoothly down subtrack

      1. Team shall review attitude data to look for biases and oscillations

      2. SpaceX shall examine subtrack rail to look for damage

   iv. Pod Monitoring Telemetry is steady and accurate

   v. Pod properly brakes based on pre-programmed software condition

   vi. If applicable, Pod levitation system functions properly

   vii. Test can be efficiently re-initialized and repeated

8. **Open-Air Hyperloop Test**
    a. This is a test in the Hyperloop, except with the doors open and thus at atmospheric pressure. This test is similar to the External Subtrack Test, except it can support higher speeds, longer distances, and navigation with the optical tape.
    b. In this test, the Pod will likely come to a stop in the middle of the Hyperloop. Thus, this test can only be run with Pods that have efficient Service Propulsion Systems.
    c. Entry Criteria
        i. Approval by SpaceX Advisors of Pod Transport Procedure
        ii. Approval by SpaceX Advisors of Pod Unloading Plan
        iii. Successful completion of full Functional Test
        iv. Successful completion of Mechanical Fit Check
        v. Successful completion of State Diagram Tests
        vi. Approval of Pod Health Check list
        vii. Approval to proceed from SpaceX Organizers
    d. Pre-Test Discussions
        i. Agreement of SpaceX Advisors and Team on speed profile (capped at 50 mph).
        ii. Agreement on whether Pod will be levitating for this test
        iii. For teams with stationary levitation systems:
            1. Verification of maximum hovering duration
            2. Explanation of when levitation begins (e.g. before Pusher begins to accelerate or afterwards)
            3. Verified duration of levitation which would result in aluminum plate damage
    e. Test Logistics
        i. NAP will be pre-installed on the Pod.
        ii. Pod will be transported via road to the Hyperloop Staging Area.
        iii. Pod will be lifted, via a SpaceX-provided forklift if necessary, onto the Staging Area, an open-air flat surface 20 feet in length.
        iv. Pod will be moved into the Hyperloop using the Pod's Service Propulsion System.
        v. Pod will perform the pre-approved Pod Health Check (sometimes called Functional Test B) in order to verify connectivity and Pod health. This must include the Pod Monitoring Telemetry
        vi. Team shall initialize Pod into the pre-tested Pre-launch State
        vii. Once both SpaceX and Team have verbally said "Go," SpaceX will initiate the Pusher
        viii. Once the run is complete, Pod enters or is placed into a pre-approved safe state and performs the Pod Health Check
        ix. If the Pod is deemed safe, Pod is removed from Hyperloop using its Pod Unloading procedures
    f. Exit Criteria
        i. Pod smoothly separates from Pusher
        ii. Pod properly transitions through its state diagram and does not brake while attached to the Pusher
        iii. Pod translates smoothly down subtrack
            1. Team shall review attitude data to look for biases and oscillations
            2. SpaceX shall examine subtrack rail to look for damage
        iv. Pod Monitoring Telemetry is steady and accurate
        v. Pod properly brakes based on pre-programmed software condition
        vi. If applicable, Pod levitation system functions properly
        vii. If applicable, Pod detected the optical tape

9. **Hyperloop Run**
    a. This is the real deal!
    b. Entry Criteria
        i. Successful completion of full Functional Test
        ii. Successful completion of Vacuum Test (powered on and under load)
        iii. Successful completion of Mechanical Fit Check
        iv. Successful completion of Navigation Test
        v. Successful completion of State Diagram Tests
        vi. Successful Completion of External Subtrack Test and/or Open-Air Hyperloop Test
        vii. Successful demonstration of levitation, whether in the Vacuum Chamber, the External Subtrack, or Open-Air Hyperloop
        viii. Approval of Pod Health Check list
        ix. Approval by SpaceX Advisors of Pod Unloading Plan
        x. Approval to proceed from SpaceX Organizers
    c. Pre-Test Discussions
        i. Agreement of SpaceX Advisors and Team on speed profile
        ii. Verification that battery capacity is sufficient for entire test (40 minutes)
        iii. If the Pusher will be accelerating the Pod to a speed greater than the Pod can maintain control if it did not levitate, verification is needed to show that Pusher Interface friction will not inhibit levitation.
        iv. For teams with air-based levitation systems:
            1. Verification of maximum hovering duration
            2. Explanation of whether levitation begins before or after Pusher begins to accelerate
    d. Test Logistics
        i. NAP will be pre-installed on the Pod.
        ii. Pod will be transported via road to the Hyperloop Staging Area.
        iii. Pods will be lifted, via a SpaceX-provided forklift if necessary, onto the Staging Area, an open-air flat surface 20 feet in length.
        iv. Pod will be moved into the Hyperloop using the Pod's Service Propulsion System.
        v. Pod will perform pre-approved Pod Health Check (sometimes called Functional Test B) in order to verify connectivity and Pod health. This must include the Pod Monitoring Telemetry
        vi. The Hyperloop Door ("Gate 1") will then be closed and the Pod Health Check will be repeated (sometimes called Functional Test C). This includes the demonstration of a continuous communications link.
        vii. The Hyperloop will be depressurized to operating pressure.
        viii. At operating pressure, the Pod Health Check will be repeated (sometimes called Functional Test D).
        ix. Pod team shall initialize their Pod into the pre-tested Pre-launch State
        x. Once both SpaceX and Team have verbally said "Go," SpaceX will initiate the Pusher
        xi. Once the run is complete, Pod enters or is placed into a pre-approved safe state and performs the Pod Health Check (sometimes called Functional Test E).
        xii. If the Pod is deemed safe, the Hyperloop Exit Door (Gate 2) is opened
        xiii. Team runs Pod Unloading procedure to place Pod onto Exit Staging area and then off of Hyperloop
    e. Exit Criteria
        i. Pod didn't break the Pusher, did not damage Hyperloop, and did not crash.

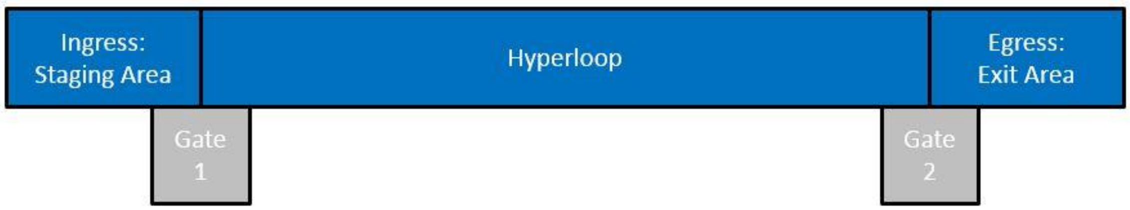
ii. Pod successfully stopped within 100 feet (formerly 50 feet) of the Hyperloop Exit Door (Gate 2). If so, congratulations!

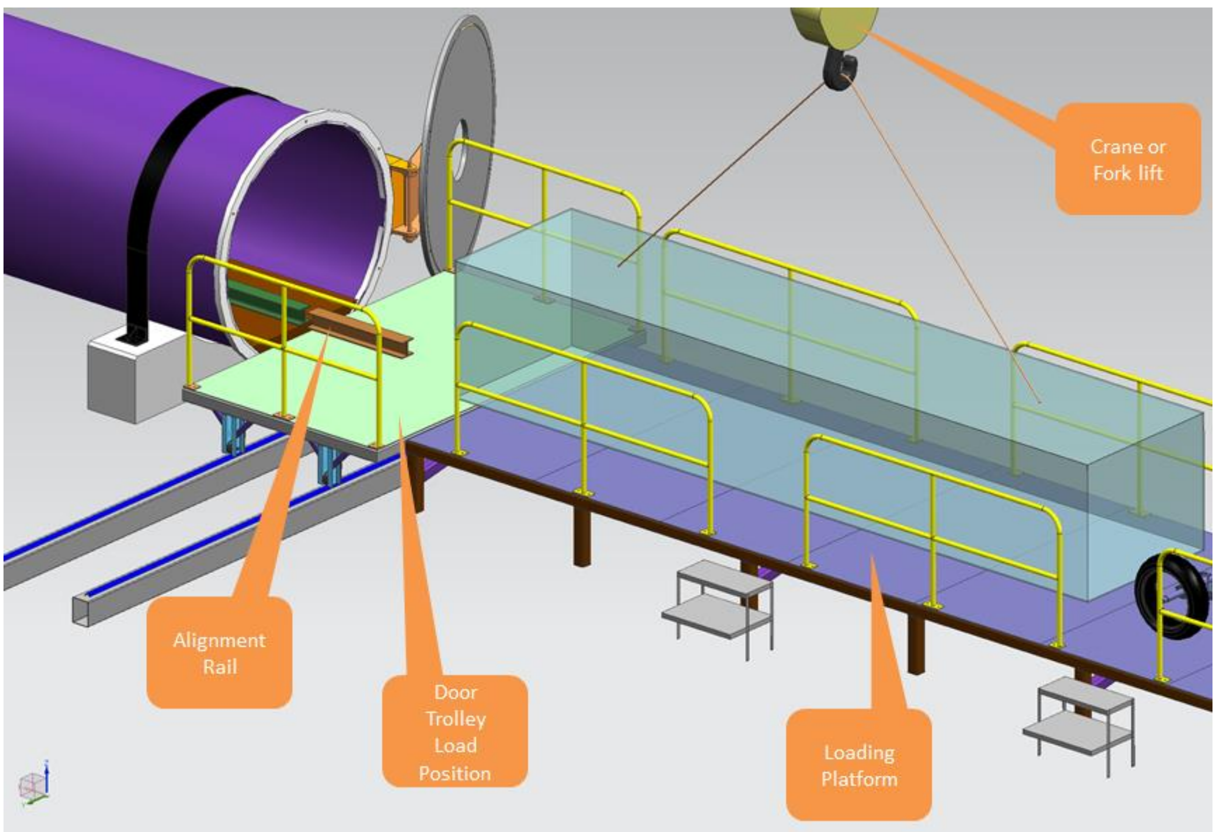
iii. Three sources of Pod data are available to evaluate Pod's trajectory:

1. The NAP's data recorder
2. The team's Pod Monitoring Telemetry
3. External sensors placed by SpaceX in the Hyperloop

Supporting Images and Diagrams

Top-Level Hyperloop Loading and Unloading Infrastructure; only forklift (not crane) is available

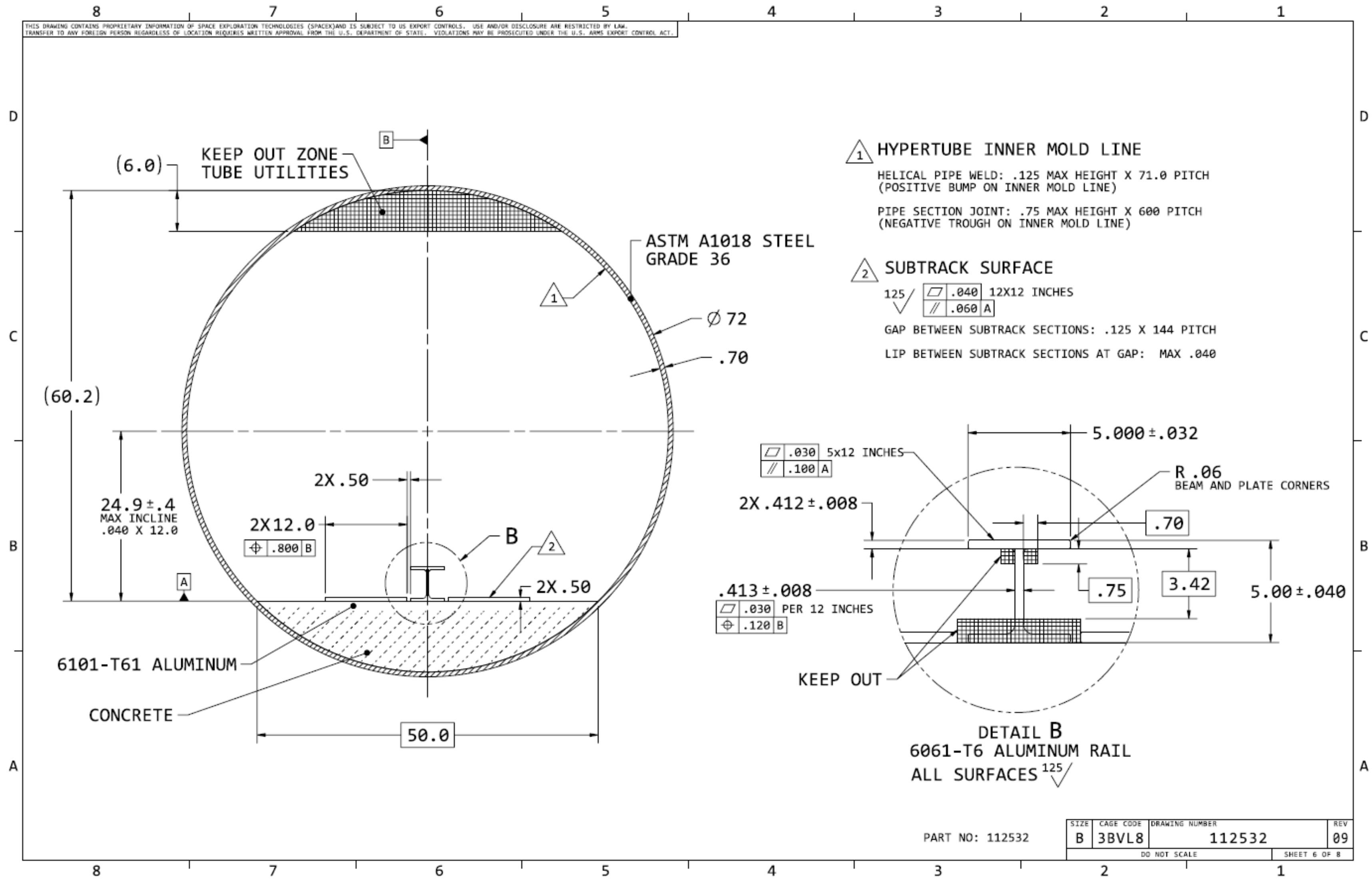




Student Team Testing in SpaceX Vacuum Chamber

Student Team Testing on SpaceX External Subtrack

Hyperloop Cross-Section



Local Area Map