HYPERLOOP
UNIVERSITY OF WASHINGTON

ElectroImpact Partnership

Design Brief created by the University of Washington Seattle’s student team for the 2015 - 2016 SpaceX Pod Competition
Finalized January 2016

Preliminary Design Briefing Overview

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University of Washington : Hyperloop

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Who we are:

University of Washington - student run organization , Diverse 40+ students :

- Undergraduates, Masters, PhDs
- **Multi disciplinary :** Mechanical Eng, Aerospace, Electrical Eng, Computer Sci, Physics, Math , Business, Design, Psych
- **Faculty Advisors :** Mechanical, Aeronautics & Astronautics and Civil Engineering
- **Multiple teams :** Aerodynamics, Propulsion, Systems, Power Distribution, Manufacturing

What are we doing:

- Developing ¼ scale passenger pod prototype to race on the California Test tack in June 2016
- Building infrastructure for Student organization to compete annually, similar to Formula SAE

What have we accomplished

- Nov 17 Preliminary Design Review: Advanced to next round , only 124 of 1200 teams
- Jan 27 Final Design Review : One of 26 teams to advance to final . Won Best Safety Sub-system

UWHL seeks Electroimpact's help in :

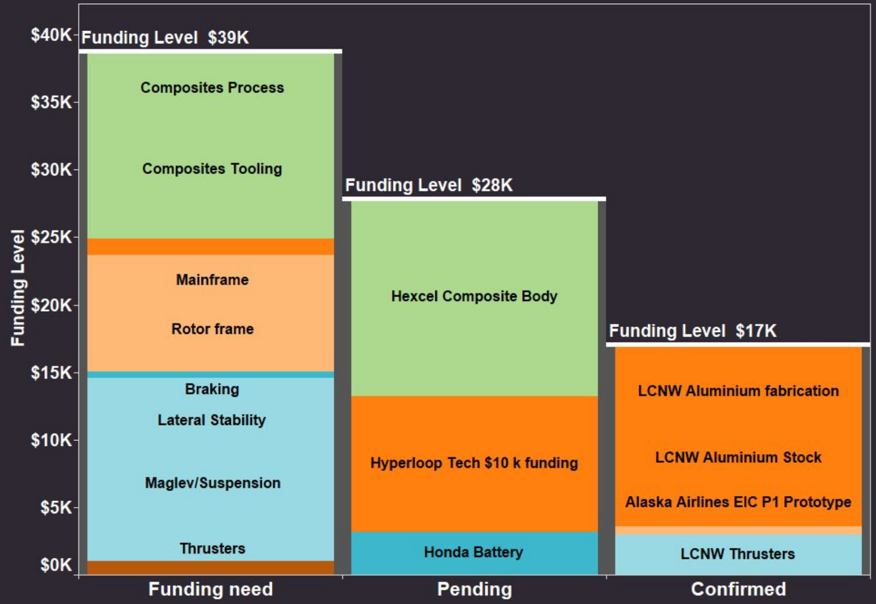
- Funding contribution
- Mentorship : Eddy Current braking design and testing , peer design reviews
- Materials donation

Electroimpact can help UW Hyperloop develop engineers !

ELECTROIMPACT

Collaboration opportunities :

- Funding balance to go : **$29,000**
    - ~$65,000 total cost to build Prototype #1 & 2
    - $37,000 pending and confirmed sponsorship
- Relevant material donation
    - Aluminium stock (sheet or tubing)
    - Neodymium magnets
    - Wiring for control and power systems
    - Actuators
- Mentorship
    - Eddy current braking and testing
    - Peer design review



Mentorship : Eddy Current Braking & Peer Design Reviews

1. **Eddy current braking**

- Testing:
  Make a 0.383in thick aluminum 6061 disk (same thickness/ material as I beam on track), with ~7in radius. Construct a way to attach a powerful motor to center of disk, as well as allowing disk to rotate with minimal friction, to simulate coasting. Bring disk to desired speed, mimicking speeds our pod will likely reach in track. Cut power to motor and let disk spin freely. Engage electromagnets.
  - Independent variable: Distance of electromagnets from disk
  - Dependent variable: Time for disk to come to complete stop; Heat generated from electromagnets
- Design:
  Have 3 pairs of a total 6 high power electromagnets be placed along the frame of the pod. The electromagnets will have a variable distance from the center of the I beam, with a minimum distance of 1 inch from the center to maximize braking force

2. **Tilt Electrodynamic Suspension (EDS) Array - Braking:**

- Vertical articulation allows the arrays to sink to a minimum off-track height *below* equilibrium during the braking phase. The brake calipers "clamp down" the pod to a fixed height, and the array can minimize separation to maximize drag effects.
- A small degree of tilt about the lateral axis will be available to level the pod parallel to the I-beam.

GENERAL

Competition

Hyperloop transportation concept published by Elon Musk and SpaceX

- Solar powered, emission free
- $7 billion alternative to the $70 billion high speed rail project in California

Jan 29th
Design Weekend

Summer 2016
California test track

Similar to Formula SAE and Eco-car :

- Multi-university competition to design and build subscale passenger pods to race in the SpaceX built test track in the summer of 2016

GENERAL

University of Washington : Hyperloop in the News

MENU

KOMONEWS.com

University of Washington team impresses billionaire Musk with "hyperloop" safety system

BY CORWIN HAECK | MONDAY, FEBRUARY 1ST 2016

Elon Musk

http://komonews.com/news/local/university-of-washington-team-impresses-billionaire-musk-with-hyperloop-safety-system

Best Safety System Design- Design Weekend January 30, 2016

GeekWire NEWS JOBS EVENTS RESOURCES DEALS ABOUT Search

MIT leads in first round of Elon Musk’s Hyperloop contest, but UW is in the race

BY ALAN BOYLE on January 31, 2016 at 7:57 pm

http://www.geekwire.com/2016/mit-leads-in-first-round-of-spacexs-hyperloop-contest-but-uw-is-in-the-race/

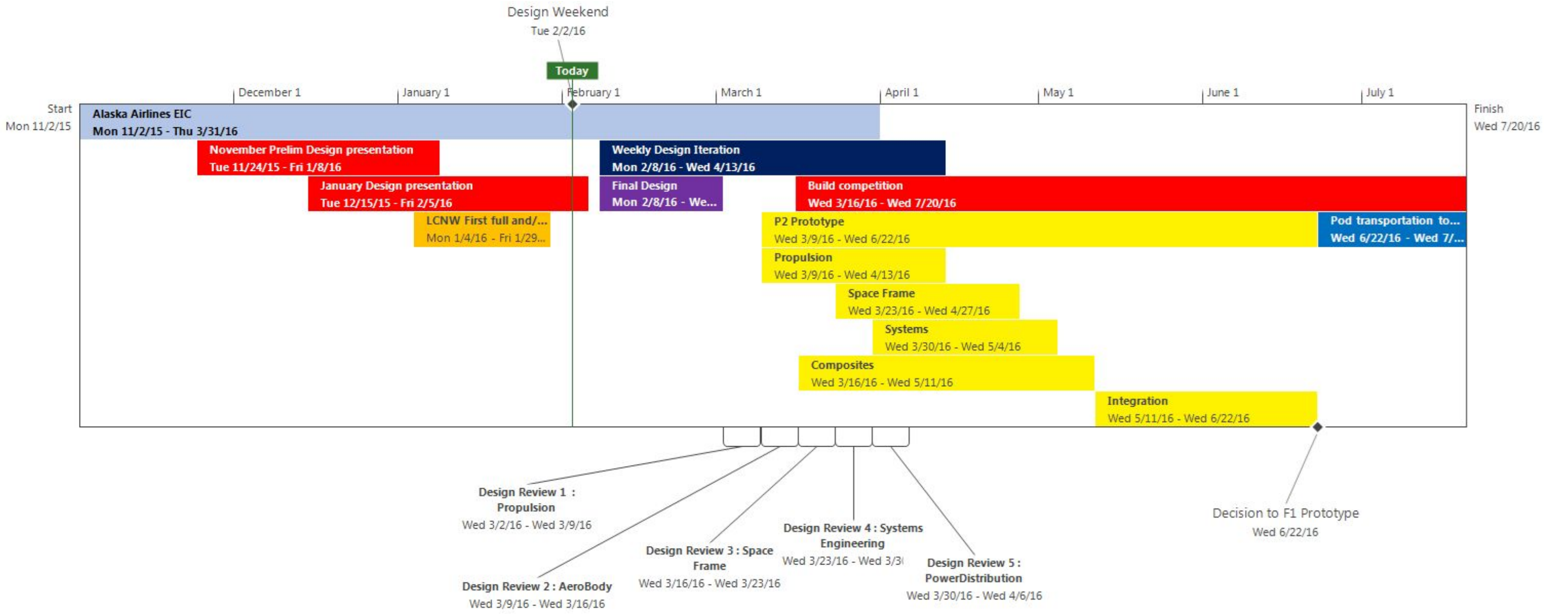
Manufacturing

Production Schedule: Transportation Ready June 22, 2016

<u>Project Plan with 500+ line items</u>

- 2 Pod builds
  - P 1 : ½ scale propulsion functional test
  - P 2 : full-size build all systems compete

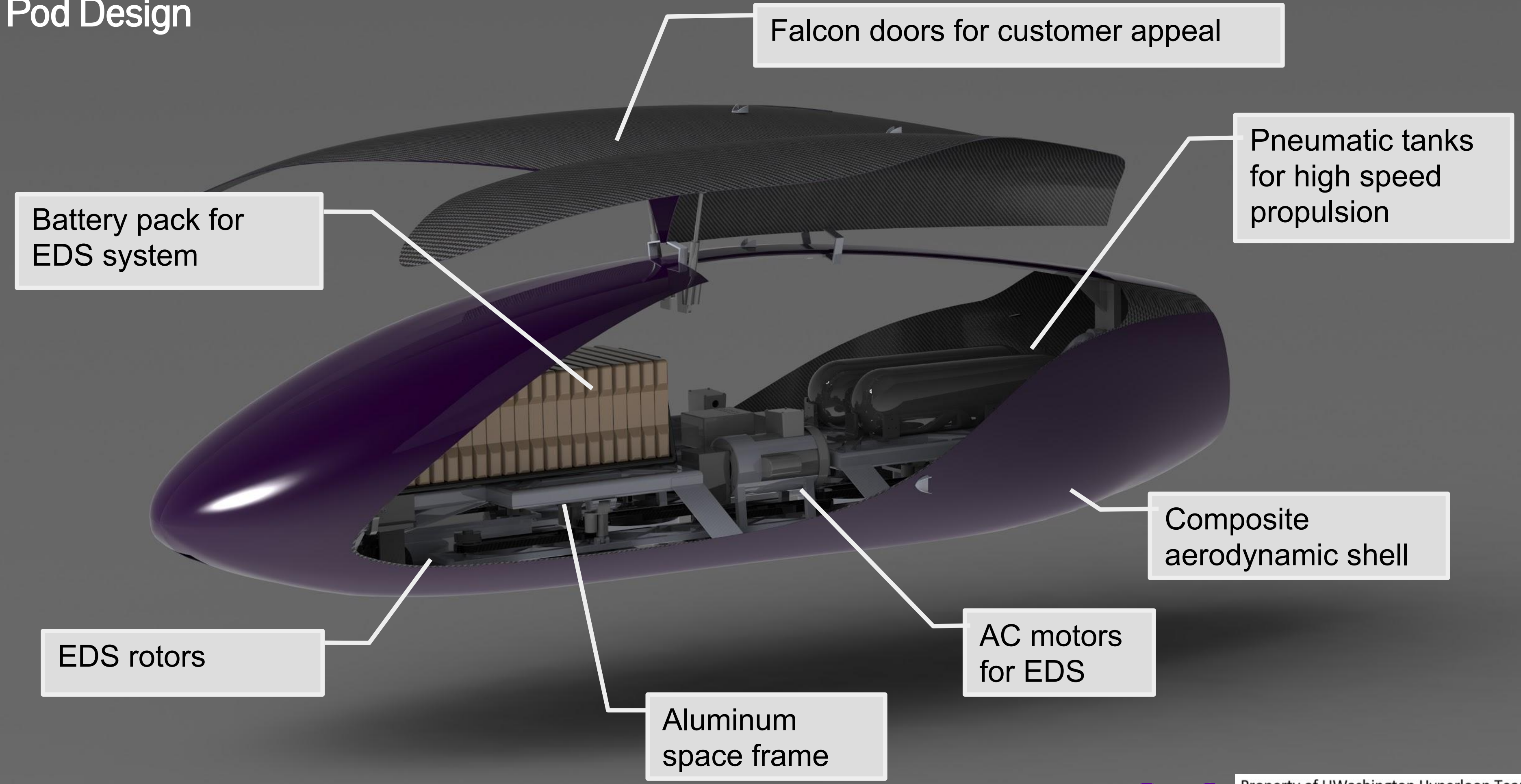
- Final Re-design: 2 - 3 weeks
- Transportation ready: June 22, 2016



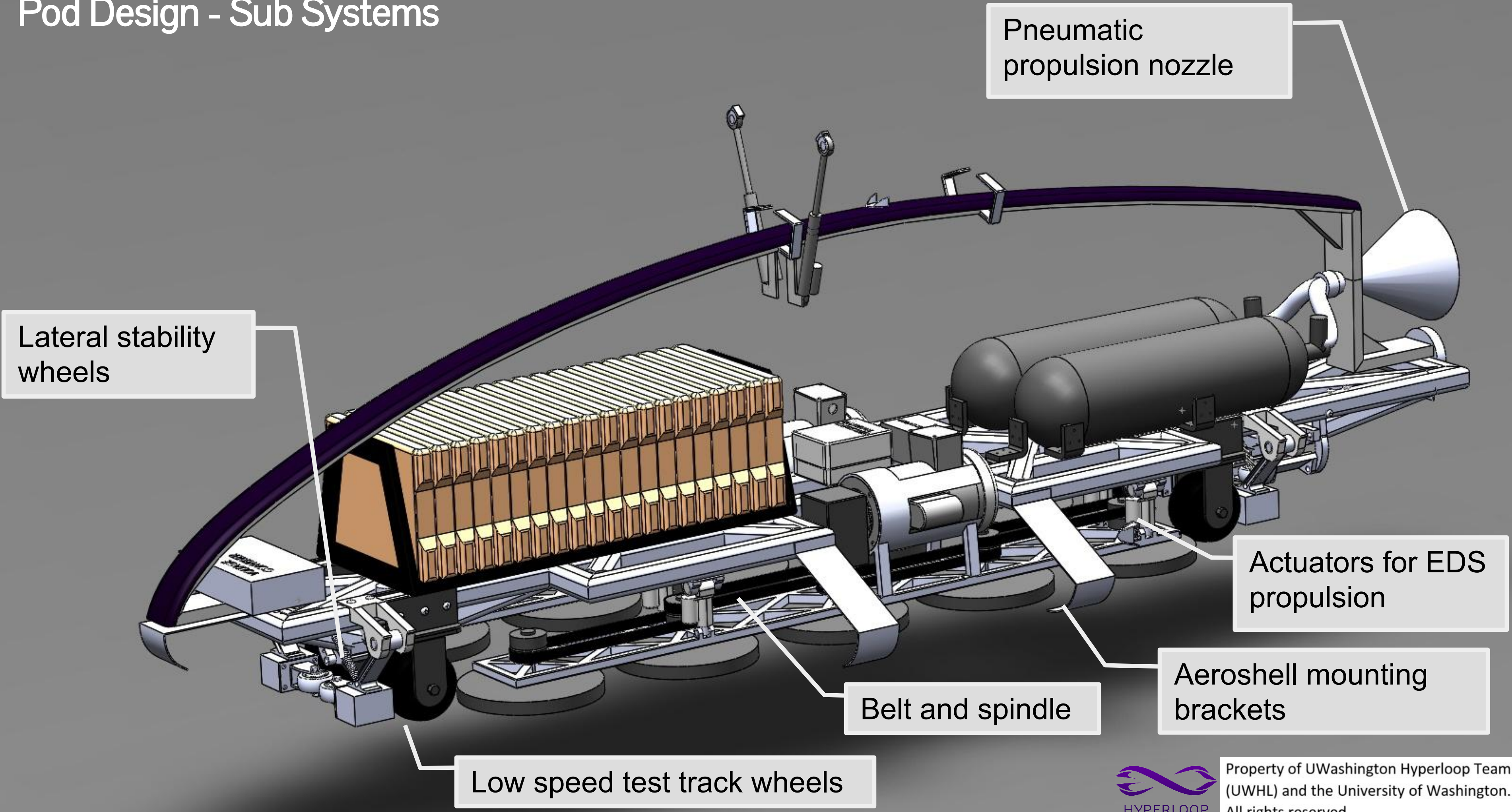
UWashington Hyperloop :

Build schedule & Design overview

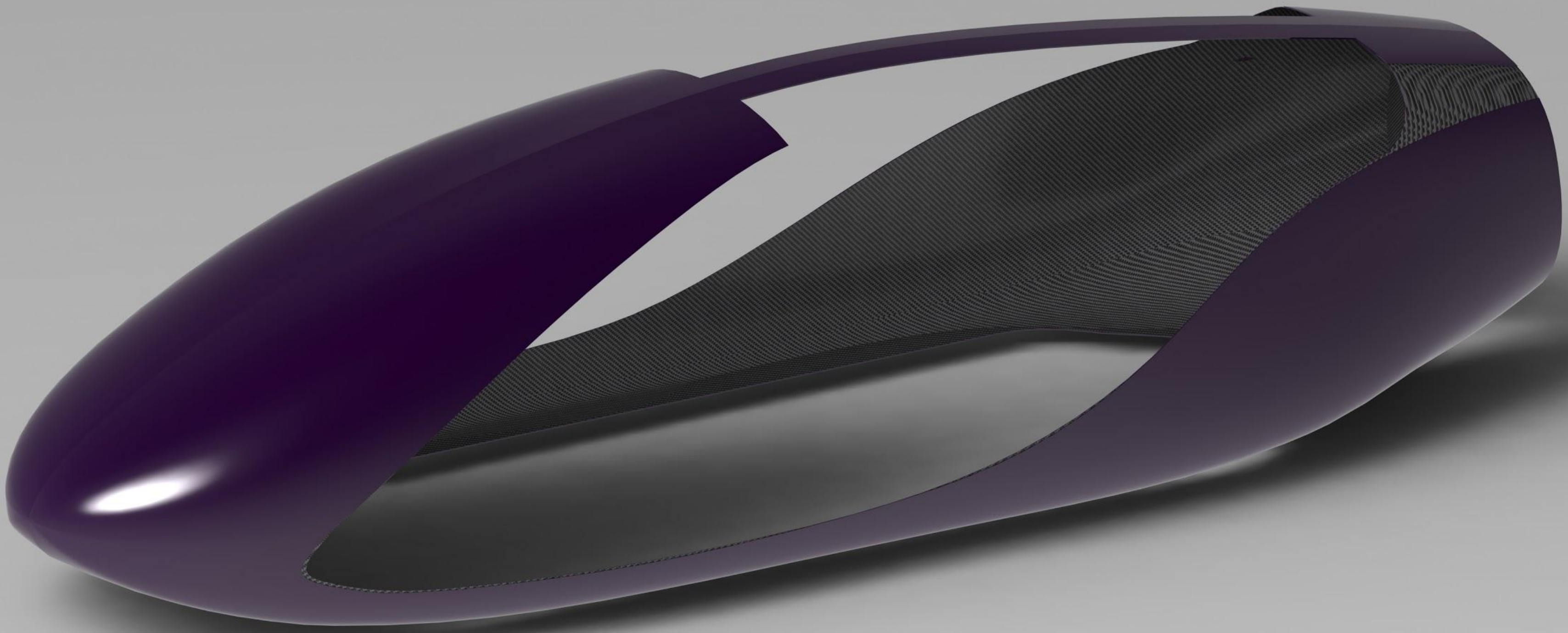
Pod Design


Falcon doors for customer appeal
Battery pack for EDS system
Pneumatic tanks for high speed propulsion
Composite aerodynamic shell
EDS rotors
AC motors for EDS
Aluminum space frame

Pod Design - Sub Systems



Pod Design - Carbon Shell



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Back up slides

Pod Structure, materials and manufacturing

Pod Mass	Weight lbs	Quantity	Total Weight
Batteries	320	1	320
Air Tanks	220	1	220
Rotors	20	10	200
Rotor Sub Frame	8	2	16
Main Frame + Rotor Sub Frame + Spine	170	1	170
Breaks	20	2	40
Wheels	20	4	40
Stability	10	2	20
Voltage Converter	50	1	50
Misc Components	30	1	30
Cooling	20	1	20
Inverter	30	1	30
Payload	300	1	300
		Total	**1456 lb**

Primary structure: Aluminum main frame

All pod components will be attached to the aluminum main frame and this will be the primary load bearing structure. Two sub frames will be attached to the main frame which will hold the propulsion rotors, motors and the drivetrain. On top of the main frame would be an aluminum spine to support and attach the carbon shell and doors with door mechanisms.

The aluminum main frame and sub frames will be made using Al 6061 T6 structural tubing, cut to size and welded together. The two subframes will be attached to the main frame using linear actuators and telescopic tubing. This is to facilitate rotation of the subframe about a central longitudinal axis and vertical motion, necessary for the propulsion system.

Pod Body: Carbon

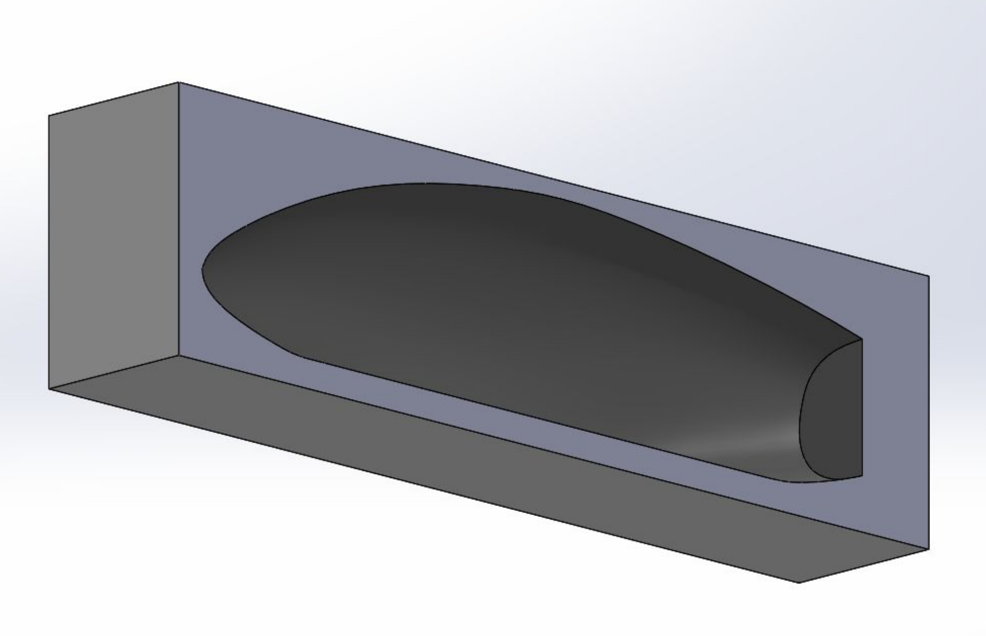
The body or outer shell of the pod is designed around an aerofoil shape for the best aerodynamic performance. The shell would be made using carbon/epoxy prepreg materials to have a light weight shell in this aerodynamic shape.

The shell would be made using unidirectional carbon/epoxy prepreg in a quasi isotropic layup $[45^o,-45^o, 0^o, 90^o]_s$. A layer woven carbon/epoxy prepreg would be added at each end of this laminate and will thus form the outermost layers to provide better protection against impact damages.

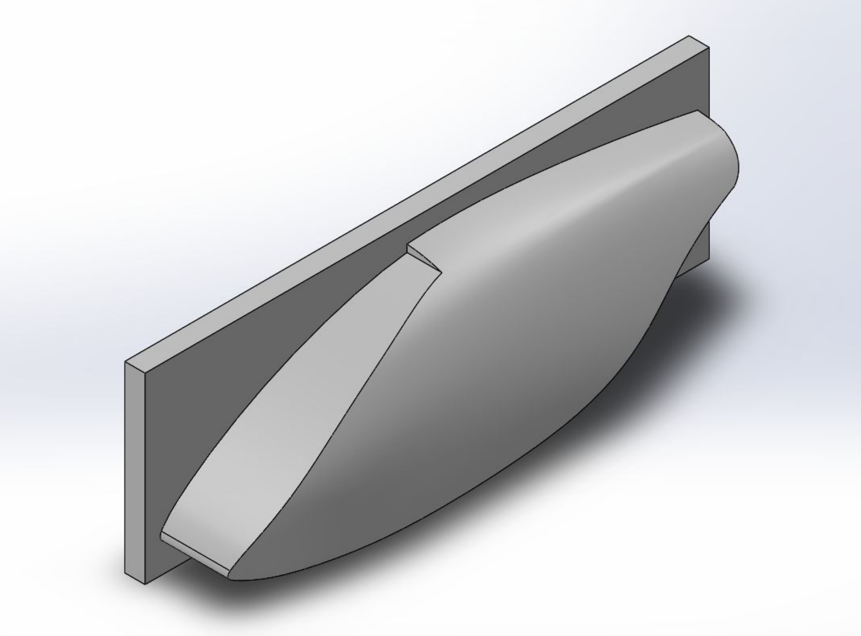
The shell will be fabricated in 11 parts: 2 doors, 8 parts to for the shell and one part to form the back. These parts will then be trimmed and joined to the mainframe and to each other using fasteners and to various attachment locations provided on the frame.

Composites Mold Foam (Tentative First Drafts)

Dimensions:
Height: 40 inches
Width: 52 inches
Length: 145 inches



Pod Mold Right Side



Left Door Mold

POD DESIGN

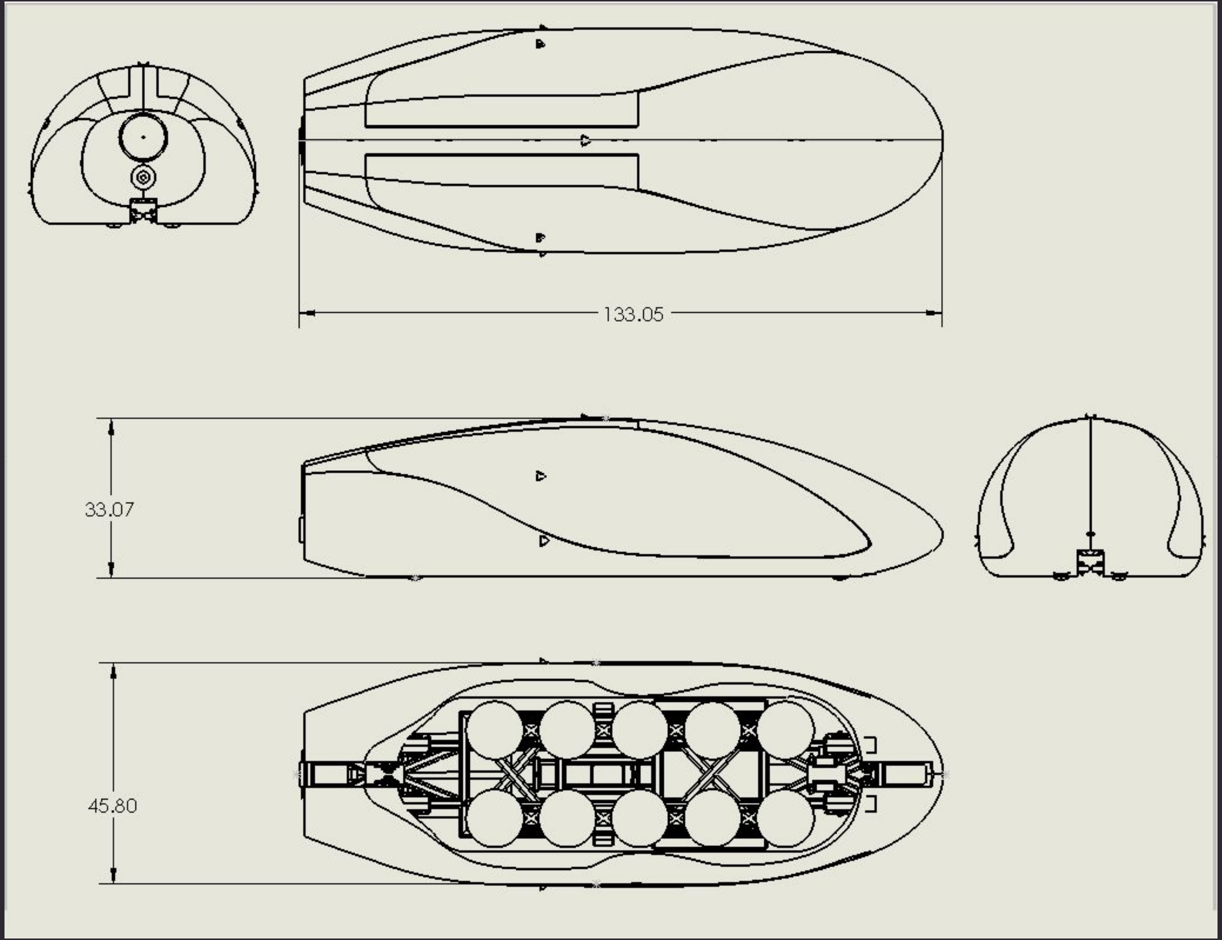
Pod Dimensions

Estimated Pod dimensions:

- Total length
  133.05 in (3379.47 mm)

- Maximum height
  33.07 in (855.98 mm)

- Maximum width
  45.8 in (1163.32 mm)



Sub Systems Slides

Pod Propulsion Mechanisms : Design decision

Detailed descriptions of the pod propulsion systems.

Overview:

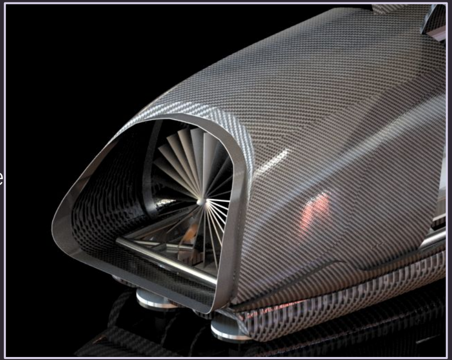
Given that we will be using the concrete pusher to bypass the acceleration phase of the pod test flight, our plan is to mount an axial electric fan at the front of the pod to rapidly transfer air from the front of the pod to the rear nozzle to prevent choking flow (and to a lesser extent serve as a propulsion mechanism).

We decided on an axial electric fan over an axial compressor fan due to the onboard pre-pressurized air tank that will serve as a low speed propulsion mechanism and help maintain speed during the coast phase of our test flight. Because of this, the efficiency requirement of the axial fan can be greatly reduced with the added benefit of increased weight savings (no cooling systems for compressed air) and power consumption savings (less electrical systems). Although the caveat to this is that we are facing a problem searching for axial electric fans that:

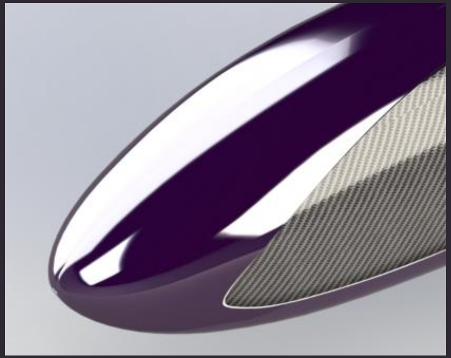
1. Efficiently operate in a low pressure environment
2. Given our pod dimensions, can handle a high CFM volumetric flow rate of air

Therefore, it is in our best interest to design a diffuser nozzle to decrease the flow rate of air at the face of the axial fan so that we can take advantage of a larger breadth of the axial electric fan market. The table on the right provides a short list of axial fans we are investigating for use inside of our pod.

P 1 : Axial Fan Design



P 2 : Diffuser Nose Design



Possible Axial Electric Fan Suppliers List (as of Nov 12 2015)	Model	Mass	Power Usage	CFM
Cincinnati Fans	TAF	150 kg *(estimate)*	8.6 kW	44490
Sodeca	HTP-71-2T-20	198 kg	15 kW	23102
Sodeca	HTP-90-4T-20	266 kg	15 kW	29458

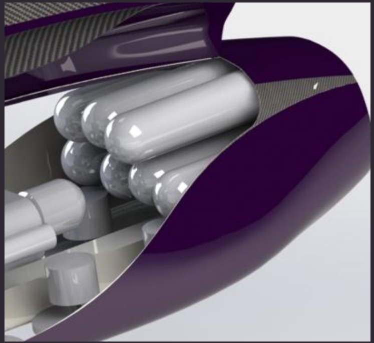
PROPULSION
Pod Propulsion Mechanisms (Continued)

Continued detailed descriptions of the pod propulsion systems.

Axial Electric Fan Design Parameters:

The figure to the right highlights the general equations that we at first were using to estimate volumetric flow rate (CFM) and power requirements (kW) for a suitable axial electric fan for our pod.

Now, implementing the OpenMDAO plugin and pyCycle thermodynamic analysis tool has allowed us to further verify our mass flow at the front face of our fan and power requirement values.



P2:
Pressurized tank system alternative to fan

Using the equations below we can solve for our axial fan design parameters.

P_1 = 100 Pa
P_2 = 150 Pa (Assuming Pressure ratio of 1.5)
T_1 = 292 K
V = 120 m/s
A_{inlet} = 0.33 m^2

γ = 1.4 (Heat specific ratio of air)
T_2 = Air Temperature after fan
$\dot{m}$ = Mass Flow entering fan
C_p = 1.005 kJ/(kg*K) Constant Pressure Specific Heat
$\dot{Q}$ = Volumetric Flow Rate
$\dot{W}$ = Power (kW)

$$\frac{P_2}{P_1} = \frac{T_2^{\frac{1-\gamma}{\gamma}}}{T_1^{\frac{1-\gamma}{\gamma}}}$$

$$\dot{W} = \dot{m} * C_p(T_2 - T_1)$$

$$\dot{m} = \varrho * V * A_{inlet}$$

$$\dot{Q} = V * A_{inlet}$$

Note for $\dot{W}$ we will also need to take into account the efficiency of the fan, we are assuming isentropic flow as a perfect fan does not exist. We are currently estimating 15% higher power output than the ideal fan power output.

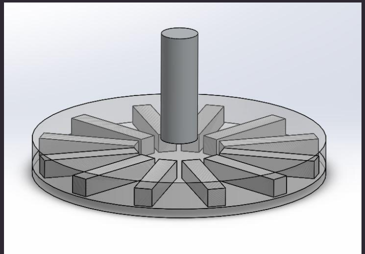
Pod Levitation Methods

Detailed descriptions of viable pod levitation methods.

Option 1: High RPM Neodymium Magnets:

This concept would work by applying angular velocity to a circular magnetic Halbach array. This causes the magnets in the array to move with a velocity relative to the aluminum track which causes eddy currents to flow in the aluminum. These eddy currents in turn produce an opposing magnetic field which generates lift on the array. The array would be produced so that the diameter of the array would be similar to the width of the track for the most efficiency in creating lift.

The following suppliers for Neodymium Magnets have been identified: KJ Magnetics, Grainger, Magnetic Hold Company, Magnet Source, United Nuclear, CMS Magnetics and Applied Magnets. 2x1/2x1/2" Neodymium Magnets cost about 4 dollars each and each array would use about 20 magnets. Adding in additional materials, each array could cost under 200 dollars, not including the motor necessary to drive the array.



Option 2: Rare Earth Metal Magnets/Stationary Halbach Array:

In order to levitate the pod with a fixed Halbach array, current would have to be applied to the aluminum track for low speed levitation, since at low speeds there is little relative motion between the array and the track. With little relative motion, there will not be enough current induced in the track to give enough opposing magnetic field and force to lift the pod. Thus the current will be needed at low speeds to boost the opposing magnetic field.

The components attached to the pod would simply be an array of magnets, so this is potentially a cheap option. However, energy would need to be applied to the track increasing the cost and complexity.

Option 3: Arx Pax:

The Arx Pax motors work in a similar fashion to the previously described rotating Arrays.

According to the Arx Pax specification sheet, the motors require 70W per kg lifted, with a pod mass of 700 kg (excluding the levitation system itself) this translates to 49kW required to lift the pod. If each motor is to lift 40kg, 18 motors will be needed and a levitation height of 7mm will result.

This is the most costly option as each motor costs $4850

Pod Braking Methods

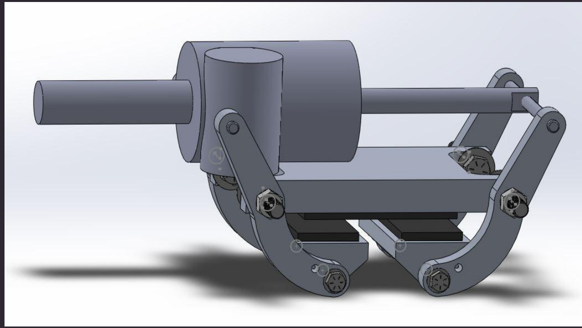
Detailed descriptions of viable pod braking methods.

1. Friction Brake:

- Linkage system clamping rubber pads onto I-beam when acted upon by a linear actuator.
  - The I-beam top flange was selected instead of the web to counter the forward pitch moment induced by the friction brake.
- At 150 m/s and a pod weight of 650kg, the brakes will dissipate 8.23 MW in the worst case scenario.
  - Using a thermal conductivity for rubber of .16 W/(m-K) and 205 W/(m-K) for aluminum, 99.9% of the heat produced will go into the aluminum raising the beams.
- During the braking phase the EDS lift will be decreased causing the top plate of the assembly to drop down onto the web of the I-beam and the arms will actuate for the pads to clamp onto the I-beam flange.
- An Enerpac ball screw actuator will be used for clamping the pads onto the beam and has more than enough capability.
  - Lowest capacity actuator is capable of delivering 1 ton of force into the pads.
  - 1500lbs are required in the actuator to provide 2.4 g of braking.

2. Tilt Electrodynamic Suspension (EDS) Array - Braking:

- Vertical articulation allows the arrays to sink to a minimum off-track height *below* equilibrium during the braking phase. The brake calipers “clamp down” the pod to a fixed height, and the array can minimize separation to maximize drag effects.
- A small degree of tilt about the lateral axis will be available to level the pod parallel to the I-beam.



Pod friction brake mechanism

Enerpac B-Series ball screw actuators

Pod Safety Information & Hazards

Safety information, stored energy features and hazardous materials within pod.

Stored Energy:

- **Electric :** Sole source electric energy within the pod will reside within the battery array, providing large amounts of continuous current and a stable voltage, at maximum power of up to 84 kW.
- **Pneumatic :** Onboard pressure vessel will be a tank that is used for scuba diving. It will hold 100 - 200 cubic feet of air at around 3000 psi
  - Aftermarket tanks

Hazardous Material Information:

- Lithium-ion batteries contain a flammable electrolyte and are kept under consistent pressure, hence, creating a possible safety risk. $LiFePO_4$ batteries are, however, more resilient to chemical reduction reactions due to strong molecular bonding. Manganese-based arrays maintain extensive thermal stability and reliability, preventing thermal runaway.

Safety features and mechanisms.

Structural Integrity:

- A certification checklist based on regulatory agency requirements (Title 14 CFR or or other appropriate regulations) as applicable to the Hyperloop Pod will be satisfied to ensure integrity of pod structure. Test or analysis supported by test will be used to satisfy the checklist
- The primary pod structure will be designed to hold all major pod components in place in case of a crash caused by failure of pod levitation and/or propulsion systems.

Standard Safety Features:

- A standard set of airbags that appear on planes and trains.
- The standard seatbelt design used in Tesla cars.
- Standard oxygen masks present in planes.

Automated Safety Mechanism:

- Real-time attitude sensors and processing systems will ensure that, in the case of an emergency, there is automatic control of pod positioning.
- Other real-time sensors will measure specific boundaries such as pressure or system temperature and send alerts to associated systems. These alerts will progress in a tiered fashion from “normal levels” to “warning levels” to “emergency levels” with each tier corresponding to an appropriate response from the associated system. This will allow us to automatically prevent onboard emergencies from occurring.

SYSTEMS ENGINEERING

Telemetry & Data Streaming

Component Listing: (as of Nov 12 2015)	Model:	Sensor Type:	Power Usage:	Quantity:
Position/velocity in tube:	TCRT5000	Optical sensor	5 V / 1 mA	1
Acceleration in tube and Vehicle attitude (roll, pitch, yaw):	LSM9DS0	Accelerometer Gyroscope Compass Magnetometer	3.6 V / 350 µA	1
Pod pressure/ temperature:	BMP180	Barometric Pressure Altitude Temperature	3.6 V / 5 µA	2
Power Consumption:	INA219	High side DC Current Sensor	3.6 V / 350 µA	3
Flow of Axial Electric Fan	FS5	Thermal Mass Flow Sensor	5 V / 200 mA	1

The following pod telemetry will be measured using sensors described below. Arduino MCU will be used to retrieve telemetry data and CAN buses will create a central networking system to allow communication between different systems of the pod.

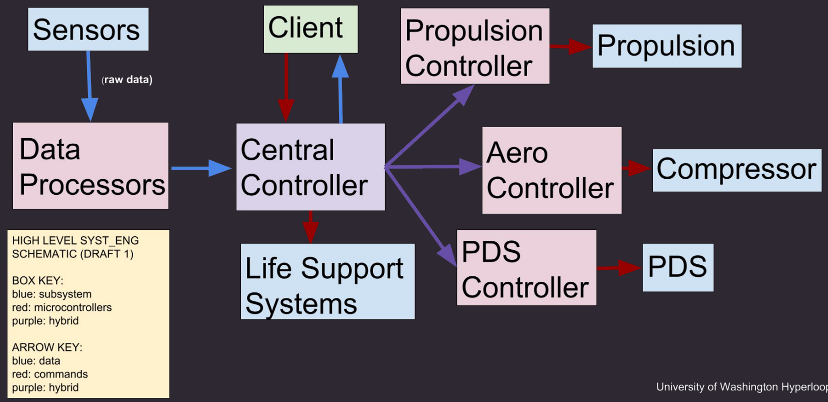
Position/Velocity in tube:
The position and velocity of the pod are measured using an optical sensor that uses the reflective marks inside the tube.

Acceleration in tube and Vehicle attitude (roll, pitch, yaw):
To more accurately measure the acceleration and altitude of the pod, an accelerometer, gyroscope, compass, and magnetometer will be utilized.

Pod pressure/ temperature:
The pod pressure and temperature are measured with a sensor that records barometric pressure, altitude and temperature.

Power Consumption:
The power consumption of different components of the pod will be measured with a high side DC current sensor.

Flow of Axial Electric fan:
The flow in/out of the axial fan and/or tank will be measured to calculate pressure inside a reservoir.



University of Washington Hyperloop

Power Consumption & Stored Energy

Detailed descriptions and mathematics on power consumption and storage.

Component	Power (kW)	Runtime (min.)	Energy Req. (kWh)
Axial Electric Fan	15	20	5
Magnetic Levitation	56	20	18.7
Systems Components + Other	2	20	0.7
Total	73	20	24.4

We will allow *20% additional headroom* for unforeseen power draw and to prevent complete discharge of battery:

$$24.4 \text{ kWh} * 120\% = 29.28 \text{ kWh} \sim 30 \text{ kWh} \quad (1)$$

Axial Electric Fan

Based on calculation from the aerodynamics and propulsion teams, the axial fan for the pod will require 15 kW for a 20 minutes runtime duration. Its total energy requirement was estimated to be 5 kWh.

Magnetic Levitation

Since the pod will be using magnetic levitation to support its weight, required power will depend on the weight of the pod. Our team will be implementing a Halbach Array, similar to the technology used by Arx Pax.

According to Arx Pax's standard datasheet, magnetic levitation consumes 70 W per kilogram of lift. If we assume pod weight to be 800 kg, magnetic levitation systems will consume around 56 kW.

Systems Components

For the systems components we estimated that the system will required around 2 kW of power and 0.67 kWh of energy.

In total, with the three components above, the estimated total power requirement results in 90 kW with total required energy of 30 kWh at a runtime of 20 min.

Battery System

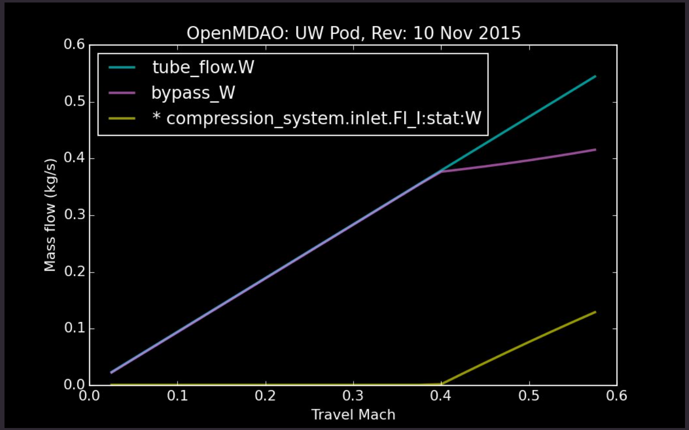
The specifications of three prospective battery arrays are as follows:

Battery Information	LG Chem Mn-Based Cell	CALB CA400	A123 Systems AMP20M1HD-A
Voltage (VDC)	96	3.2	3.3
Continuous Current Draw (A)	45	400	19.6
Maximum Current Draw (A)	205	2000	364
Battery Chemistry	$LiMn_2O_4$	$LiFePO_4$	$LiFePO_4$
Internal Resistance at 40° (Ω)	0.15	0.40	0.55
Operating Temperature (°C)	-35 - 55	-20 - 55	-30 - 55
Capacity (Wh)	4320	1280	65

AERODYNAMICS

Profile & Statistical Aerodynamics

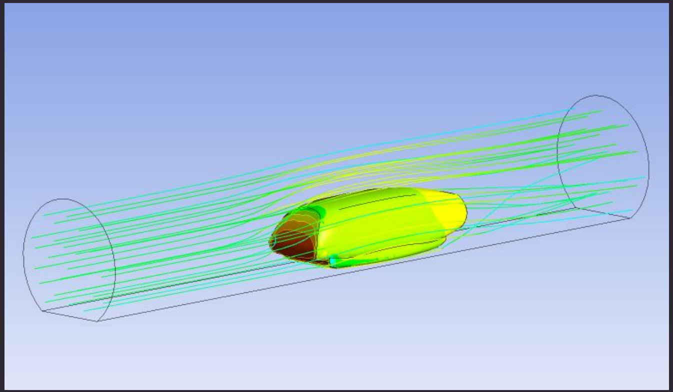
Details on pod shape + statistics and analysis for current profile.



Mass flow estimates

‡choked Mach of 0.9 is assumed, allowing for a margin of error

Inlet Area	733.9 in^2	0.4737 m^2
Maximum Cross-Sectional Area	1323.33 in^2	0.8538 m^2
Approximate‡ Kantrowitz Limit	Mach 0.4	306.9 mph



Though a fan is not needed to overcome the Kantrowitz limit at test speeds up to at least 300 mph, a fan and/or a diffuser at the inlet will be used to reduce pressure at the front of the pod (see red region on model) and improve scalability for different tube sizes and travel speeds.

Team Info Slides

Current Sponsors

LCNW SOLIDWORKS ANSYS openMDAO MATLAB

The material in this presentation has been prepared by UWashington Hyperloop of the University of Washington, Seattle, USA (UWHL) and is general background information about UWHL's activities current as at the date of this presentation. This information is given in summary form and does not purport to be complete. Information in this presentation, including forecast information, may change at any time due to design corrections and revisions, and should not be considered as a final design. UWHL does not undertake any obligation to publicly release the result of any revisions to these forward looking statements to reflect events or circumstances after the date hereof to reflect the occurrence of revised information. While due care has been used in the preparation of forecast information, actual results may vary.

Unless otherwise specified, all information is currently valid as of November 13, 2015.

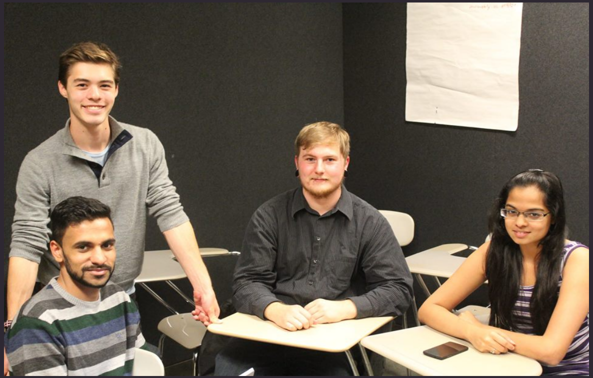
GENERAL

Mission Statement + Goal

Learn. Innovate. Build . Test. Sustain. Evolve.

The goal of the UWashington Hyperloop Team is to accelerate the advent of sustainable transport by raising awareness of futuristic, zero emissions mass transportation systems. Big leaps in technology are needed and naturally invite a high level of scrutiny. New technology must be held to a higher standard of safety than what has come before.We plan to exceed the expectations and the competition.

Our team is uniquely positioned to leverage the knowledge and resources of the academic community at the University of Washington and our local aerospace industry.



GENERAL

About UWashington Hyperloop

Evolution, not iteration.

Highlights:

- University of Washington campus
    - Reuters rated as World's #1 most innovative public university and #4 overall
    - On campus CoMotion Labs Makerspace and Kirsten Wind tunnel supports prototyping
    - Strong connections to local aerospace industry
    - Leader in sustainability in the northwest
- Necessity for sustainable transport
    - Transportation industry responsible for 21.4% of rejected energy (LLNL.gov)
    - Only a technological leap can accelerate the slow 5% annual improvement of average EPA fuel economy
- Breadth of team members/advisors
    - Multidisciplinary : Engineering, Physics, Math, Design, Psychology , Business
    - Diverse cultural background : 39 Students
- Intention to design **AND** build a pod
    - We plan to design, test, and manufacture a fully functioning pod to compete with in the June.
- Plan beyond the competition
    - Develop annual cycle to represent engineering team, similar to SAE held competitions
    - Develop a proposal for the Pacific Northwest implementation of the Hyperloop

Team Directors & Faculty Advisors

Michael Chamerski
Founder / Director
Power Distribution & Storage // Public Relations Team Lead
Major: Applied Physics

Malachi Williams
Director
Propulsion // Manufacturing Team Lead
Major: Civil / Mechanical Engineering

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Professor Breidenthal obtained his doctorate degree in Aeronautics at the California Institute of Technology in 1979. He has received support from the Air Force Office of Scientific Research, the National Science Foundation, NASA and Asea Brown Boveri, Ltd. of Switzerland. He has done consulting work for The Boeing Company, Rocketdyne, ARCO Alaska, U.S. Gypsum, Peerless Manufacturing, Asea Brown Boveri, Learjet, Vornado, Mallen Research and Centriflo.

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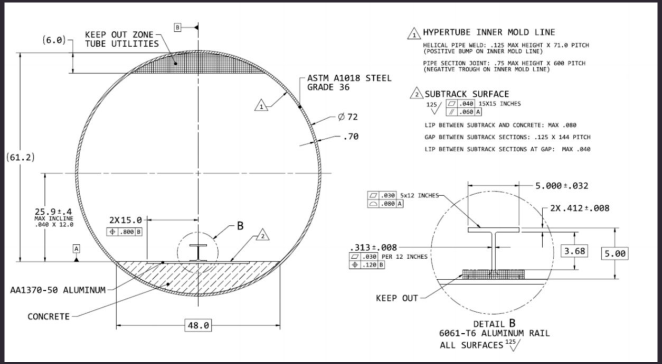
Aditya Sridhar	*Aerodynamics*	Dante Brown	*Aerodynamics*	Phu Phan	*Aerodynamics*
Ahmed Elayouty	*Business Mgmt.*	Edgardo Ferrer	*Propulsion*	Randy Lirano	*Power Dist.*
Aishwarya Mandyam	*Systems Eng.*	Garrett Allen-Dunn	*Aerodynamics*	Ravikumar Abilash	*Business Mgmt.*
Akshay Chalana	*Systems Eng.*	Griffin Kaston	*Business Mgmt*	Reza Eghbali	*Propulsion*
Amrutha Gujjar	*Systems Eng.*	Jaclyn Rainey	*Manufacturing*	Rigoberto Orozco	*Power Dist.*
Anthony Grigore	*Power Dist.*	Jasdip Singh	*Power Dist.*	Ted Coleman	*Propulsion*
Arjit Heer	*Aerodynamics*	John Davis	*Propulsion*	Zach Ives	*Propulsion*
Arun Madav Somasundaram	*Power Dist.*	Justin Kim	*Manufacturing*	Gaurav Mukherjee	*Propulsion*
Begum Birsoz	*Propulsion*	Leanne Su	*Manufacturing*	Mathias Hudoba	*Propulsion*
Brent Schroeter	*Aerodynamics*	Luke Marcoe	*Public Relations*		
Colin Summers	*Power Dist.*	Morenike Magbagbeola	*Systems Eng.*		

Summer 2016 : Race in California



California test track is under construction for summer of 2016.
Teams will “race” their prototype on the ~ 1 mile test track .

★ 325 of the 2500 points (13%) are directly related to our fabrication processes.
LCNW’s support to **prototype** and **apply Design-For-Manufacturing** will improve scores.

Judging Criteria Total Points of 2500 :

- **Category 1 Final Design and Construction** **500 pts**
  - Overall Quality of Construction **100 pts** ★
  - Overall Cost of Materials (normalized per payload mass) **100 pts** ★
  - Levitation System **75 pts** ★
  - Braking System **75 pts**
  - Ability to Economically Scale **50 pts** ★
  - Power Consumption (normalized per payload mass) **50 pts**
  - Payload Capability (as % of overall mass) **50 pts**

- **Category 2 Safety and Reliability** **500 pts**
  - Structural margins of safety and design cases **100 pts**
  - Pod-Stop Command 100 Safety in Operations **50 pts**
  - Fault tolerance of braking system **50 pts**
  - Fault tolerance of levitation systems **50 pts**
  - Fault tolerance of other systems **50 pts**
  - Loss of power contingency **50 pts**
  - Tube breach contingency **50 pts**

- **Category 3: Performance in Operations** **500 pts**
  - Efficiency of transport from Staging Area to Hyperloop **100** Efficiency of Functional Tests **100 pts**
  - Efficiency of connection to the Operational Propulsion Interface **100 pts**
  - Efficiency of transport from Hyperloop to Exit Area **100 pts**
  - Pod is removed from the tube without requiring tube pressurization **100 pts**

- **Category 4: Performance in Flight** **1000 pts**
  - Total distance Pod travels **200 pts**
  - Minimization of system drag **200 pts**
  - Functionality of Pod Braking/Deceleration System **200 pts**
  - Tightness of Lateral Control around Hyperloop center-line **100 pts**
  - Attitude Control System **100 pts**
  - Comfort of Ride (per measured vibration environment) **100 pts**
  - Reliability of Data Stream and DAQ Software **100 pts**