HYPER BULLS

UNIVERSITY AT BUFFALO HYPERLOOP TEAM

University at Buffalo
School of Engineering and Applied Sciences

Sub-Systems

- Levitation
- Structure/Aerodynamics
- Power Systems
- System Dynamics
- Braking
- Navigation and Control
- Propulsion
- Materials
- Suspension
- Summary of Hazardous Systems and Safety

POD OVERVIEW

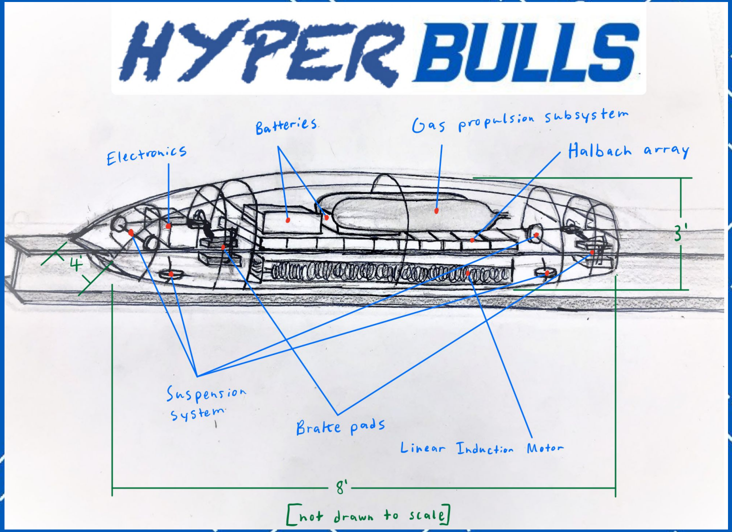
Innovation:

Utilizing hybrid linear induction/gas thrust hybrid propulsion and braking system

Utilizing a Halbach magnet array to generate levitation - effectively removing friction at high speeds

Estimated dimensions:
- Length: 8 ft
- Width: 4 ft
- Height: 3 ft

Estimated sub-system mass:
- Batteries: 100lbs
- Gas tanks: 75lbs
- Shell: 10lbs
- Frame: 20lbs
- Linear Induction Motors: 100lbs
- Neodymium magnets: 50 lbs
- Navigation and control: 10 lbs



Team Structure and Advisors

Consulting Faculty: Dr. Andrew Olewnik(Advisor), Dr. Minghui Zheng
Team Captains: Yash Kishore, Ian DesJardin, Josh Borsykowsky

Levitation: Yash Kishore, Josh Jeong, Matt Simkulet, Rayan Ray

Navigation: Ian DesJardin, Ryan Flora, Brian Scorcia

Propulsion: Josh Borsykowsky, Joshua Duell, Luke Miller, Hassib Rustemi

Braking: Alexandra Marusewski, Joaquin Fontanez-Vargas, Clayton Markham, Dylan Sandler, Michael Chu, Brian Scorcia, John Grabda

Power systems: Ryan Flora, Ben Coleman

Materials: Connor Parrish, Michael Signore

Aerodynamics: Maximilian J. Kapitonoff, Josh Borsykowsky, Connor Parrish

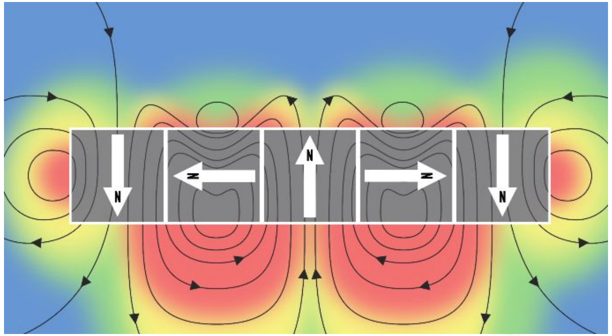
SUSPENSION SYSTEMS - LEVITATION/WHEELS HYBRID

WHEELS - until ~ 40 mph, when electric field generated is strong enough to generate lift.

MAGNETIC LEVITATION - Utilizing effect of Halbach arrays.

Halbach array - Using permanent room-temperature powerful neodymium magnets on the underside of the pod in the orientation shown in the figure. This orientation produces a much more significant magnetic field on one side of the array, and when the pod begins to move along the track it will begin to generate lift.

The Inductrack, as its name suggests, produces levitating force by inducing electric currents in the track. Moving a permanent magnet near a loop of wire will cause a current to flow in the wire. When the Inductrack pod moves forward, the magnets in the Halbach arrays induce currents in the pod's coils, which in turn generate an electromagnetic field that repels the arrays. As long as the pod is moving above a low critical speed of a few miles per hour-a bit faster than walking speed-the Halbach arrays will be levitated above the track's surface.



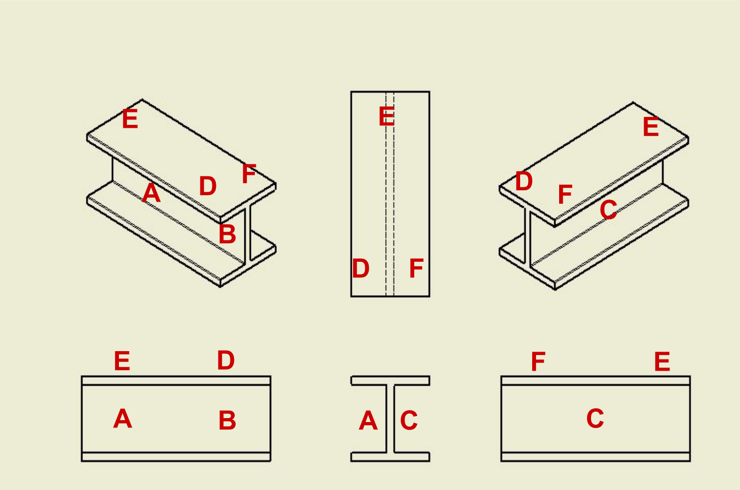
https://www.youtube.com/watch?v=pCON4zfMzjU

https://aip.scitation.org/doi/full/10.1063/1.2162475
https://www.theverge.com/2016/5/9/11636460/hyperloop-transportation-passive-magnetic-levitation-inductrack-richard-post

SUSPENSION SYSTEMS - LEVITATION/WHEELS HYBRID

WHEELS/BALL BEARINGS

- A set of 3 wheels will bear the weight of the pod during loading/initial acceleration (0-40 mph) and deceleration/braking.
- Basic suspension technology will involve a set of steel springs stretched over the top of the axlebox.
- Wheels fitted with ball bearings are preferred due to their friction reducing capabilities.
- A set of 3 non-weight-bearing wheels will align the pod by contacting the inner vertical sides of the track.



Three non-weight-bearing wheels (A, B, C) contact the vertical section of rail for stabilization purposes. Asymmetry will remove the need for one wheel and reduce the weight of the pod.

Three weight bearing wheels (D, E, F) will contact the top of the rail during the specified periods.

The feasibility of the air bearing levitation system is scrutinized by various conditions imposed by both the track and conditions which are established by both the conditions of the track and the conditions in the hyperloop:

- The track also has many uncertainties. One of the major issues would be the presence of seams on the track. Any seam on the track with a seam of 5-10 microns or greater for a system of air pads would result in system failure.

- There is the issue pertaining with putting enormous amounts of shear loads on the air bearing systems which are in the pod. The tank quickly becomes unfeasibly in such gap heights supporting the system of weight in terms of tons.

- Establishing complete levitation would require a huge amount of pressure in the terms of 10^3 psi. In the process of using a threaded hole pads the system would lose efficiency as the higher the air pressure in the gap the higher the efficiency loss.

SUSPENSION SYSTEMS - Challenges of Air Bearings

STRUCTURE - AERODYNAMICS

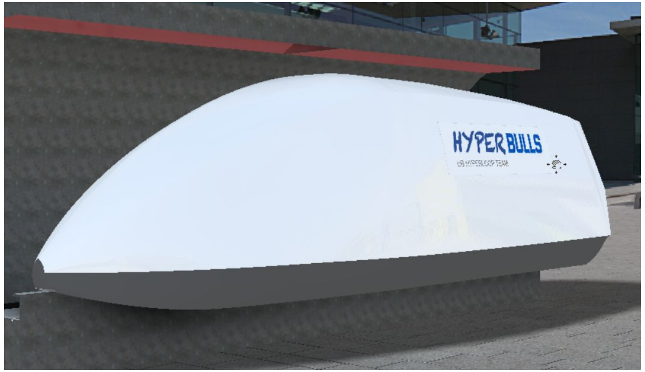
GOAL: CONSTRUCT A SHELL THAT WILL MINIMIZE DRAG AND CROSS SECTIONAL AREA AND VOLUME BASED OFF PACKAGING REQUIREMENTS

Considerations:

- While we expect the actual mass to be lower, we've done our calculations assuming the maximum weight of 3300lbs
- Interaction between air in tube (still not perfect vacuum) and walls
- length of the pod
- production of trailing vortices
- potential lift produced
- pressure drag
- induced drag
- the Kantrowitz limit and production of shock waves, and compressible flow,

The Kantrowitz limit is the most limiting in the pod's performance.

Important to note: The hyperloop tube is not a perfect vacuum, therefore by decreasing the pod's cross sectional area and increasing distance between pod and walls, we will reduce the "syringe" effect.



COEFFICIENT OF DRAG: ~0.35

SAFETY CHECK:

Heavy priority on minimizing cross-sectional horizontal turbulence forces, as at high speeds the pod "rocking" on the track will become significant concern

POWER SYSTEMS

OBJECTIVES:

- Utilize all stored potential energy in the battery during one run
- Deliver highest possible current to the linear induction motor to generate greatest acceleration

4000W Absorbed Glass Mat (AGM) batteries will be used to provide 1070A for at least 30 seconds before the voltage drop is too significant to power the linear induction motors. In between the DC battery and linear induction motor an inverter will be used to convert the DC current to an AC current. This is due to the 3-phase AC power requirement for the linear induction motors.

A separate Lithium Ion battery will provide 7.2V to power all of the electronics on the pod

FUTURE OBJECTIVE:

- Run tests to create discharge and temperature curves over time in a vacuum

https://4xspower.com/shop/12v-agm/d-series/d6500/

SAFETY CHECK:

Safety benefits of absorbed glass mat batteries:

- Negligible risk of spill/acid leakage
- Suitable at low pressures
- Long shelf life

POWER SYSTEMS SAFETY PRECAUTIONS

ACTIVE HEAT MONITORING

- Using the feedback system in conjunction with the temperature sensor we will cut the power to the linear induction motors if the temperature of the battery and pod reach an unsafe level.

- We will be using 0 gauge wire at a maximum length of 4’ to ensure the resistance is not too high and to maintain safe temperatures. The maximum acceptable amperage would be 1250A at this length.

- We have included a safety factor of 10% for calculating length due to the uncertainties of the thermodynamics in the vacuum

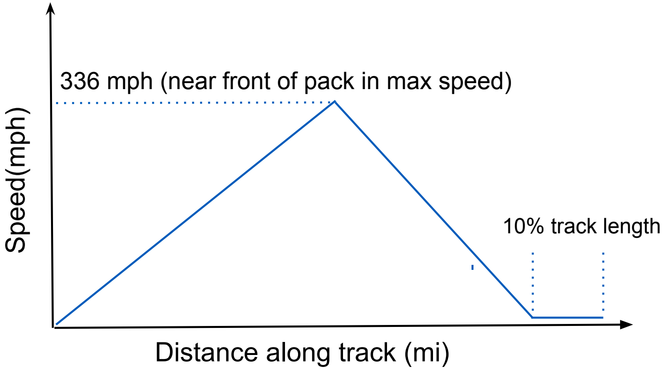
https://www.amazon.com/KnuKonceptz-Kable-Gauge-Power-increments/dp/B004Z0WQZS?th=1

SYSTEM DYNAMICS DESIGN

- Conservative assumptions were made to create a robust design. These assumptions were used for all simulation calculations.

  *Note: We assume the maximum value for pod mass - final pod design will be lower, but for our calculations we assumed the highest possible value

- Given the assumptions, the following speed profile was simulated:



Assumptions:

- ❑ Mass of Vehicle: 3300 lbm
- ❑ Perfect Vacuum
- ❑ Braking Force Needed: 6700 lbf
- ❑ Braking Time: 7.0 s
- ❑ Propulsion: 6520 lbf
- ❑ Max Speed: 336.0 mph
- ❑ Distance Spent Braking: 1807 ft
- ❑ Distance Spent Accelerating: 1880 ft
- ❑ Length of track 4100 ft
  - ❑ 10% Track Length Margin

BRAKING SYSTEM

HYBRID BRAKING SYSTEM - ***combining induced eddy current braking, gas thruster braking, and contact pad brakes***

STAGE ONE (top speed to 22 mph):

- Pressurized air thrusters activate
- Pressure control valve maintains near constant thrust output, before dropping as tank empties
- Current is sent through linear induction motor in reverse
- Eddy current braking

STAGE TWO (22 mph to 0 mph):

- Engage rubber contact brakes
- Direct contact with aluminum rail
- Produces more heat, which is why they are activated at lower speed, ensuring sub track temperature is raised no more than 50 degrees F

Goal: Achieve 7036 lbf of braking force over 7 seconds, giving a deceleration of 2.13*G*.

BRAKING/PROPULSION - COMPRESSED AIR THRUST

- The pod will use a cold gas thruster to decelerate from top speed. Note* cold gas thruster can also be used for acceleration to top speed.
- Compressed air will be stored in pressure tanks on the pod.
- Pressure control valve will regulate rate of mass flow, ensure near constant thrust
- There will be one main tank and one failsafe tank that is 75% the size of the main.

SAFETY CHECK:

Using air minimizes risk of potential fire hazard

Using pressure tank/nozzle system certified for use in vacuum pressure minimizes risk of gas leaking

Failsafe tank ensures pod has more than enough stopping power

LOGISTICS

Using one tank at 5000 psi, with a nozzle radius of 0.669 inches:

The pod can accelerate at 2.1 G

Can stop the pod from (or accelerate to) a max speed of 336 mph in a distance of 1769 feet over 7.18 seconds.

TESTING

Full depressurization tests will be run with tanks held in place, verifying consistent force outputs

COMPRESSED AIR THRUST

CALCULATIONS

Using general thrust equations, it was calculated based on the previous assumptions the gas thrusters can generate 7036 lbf of force, both during acceleration and deceleration.

Assuming a top speed of 336 mph, this would result in a 7.18 second stopping time.

*This is for a system *only* utilizing gas thrust - finalized hybrid system will have improved numbers

Variables	Value
Gas Pressure (Pa)	3.45E+07
Ambient Pressure (Pa)	8.62E+02
Nozzle Area (m^2)	9.08E-04
Mass of Pod (kg)	1.50E+03
Frictional Force Value (N)	0.00E+00
Gas Constant for air	2.87E+02
Temperature(K)	2.71E+02
Max Speed Reached(m/s)	1.50E+02
Volume of Gas Used(m^3)	9.85E-05
Stopping Time(s)	7.18E+00
Fluid Density (kg/m^3)	4.44E+02
Mass Flow Rate (kg/s)	6.09E-03
Exaust Velocity(m/s)	3.94E+02
Thrust(N)	3.13E+04
Acceleration(m/s^2)	2.09E+01
Acceleration(g's)	2.13E+00
Stopping Distance(m)	5.39E+02

BRAKING - INDUCED EDDY CURRENTS

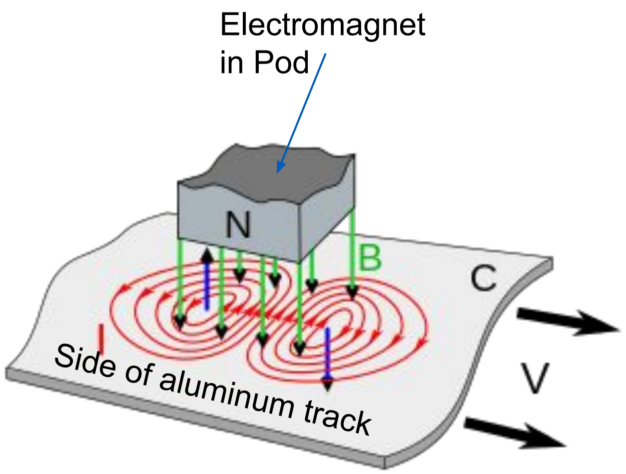
HOW EDDY CURRENT BRAKING WORKS

The pod contains electromagnets on either side of the aluminum track, oriented so that their north poles face the left and right sides of the track.

When the magnet array moves translationally, the moving magnetic field generated from the magnets induce circular eddy currents in the aluminum track. The eddy currents then have their own magnetic field which creates a force opposite to the line of motion of the magnet array, slowing the pod.

This phenomenon can be explained by the Lorentz force, Lenz's law, Faraday's law of induction, and Ampere's law.

This eddy current braking system can be achieved using the same electromagnets as the linear induction motor, just by reversing the direction of the current.



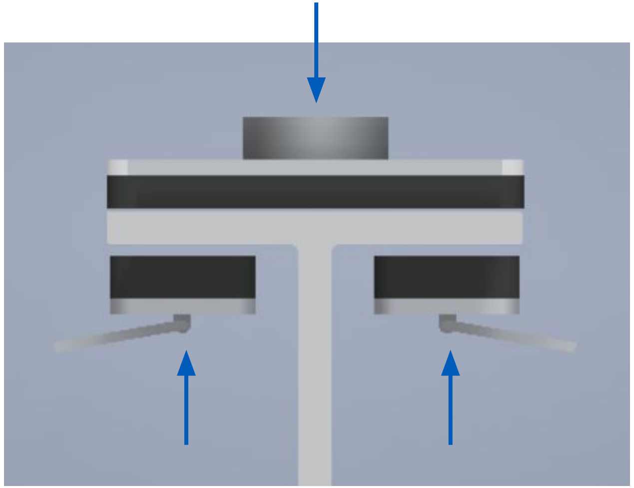
https://en.wikipedia.org/wiki/Eddy_current_brake

BRAKING - BRAKE PADS

A hydraulic system will be used to clamp the brakes against the track with rubber pads which are non-abrasive on metal

Under ideal circumstances, the friction coefficient of dry rubber on dry aluminum is 0.76. With a 20% safety margin to account for changes in heat and specific compounds, a coefficient of friction of 0.6 is assumed.

Compressed hydraulic fluid will supply necessary pressure to generate normal forces which push down on main track and push up on the inner T-bar in order to oppose forces.



SAFETY CHECK:

- Friction brake system designed so that they can be deployed at higher speeds
- Anti-lock pulsation system prevents lock-up of the brakes
- If an electrical failure were to occur, friction brakes are automatically deployed by use of fail-safe braking system
- The fail-safe system or deploying brakes earlier than expected may cause damage to the brake pads and track if deployed, but could save lives and infrastructure
- Both the eddy current and friction brakes will release heat, some of which can be dissipated using the cooling effect of the adiabatic expansion of pressurized gas from the cold gas thruster

NAVIGATION AND CONTROL COMMUNICATIONS

- The M9 Radio connected to team laptop first communicates with the on board pod M9.
- The on board M9 is connected to an ethernet switch which serves as a basis for our feedback loop.
- The loop connects to a “control” Raspberry Pi which will be used to control the pod’s on board functions.
- The control Pi is wired to our propulsion braking system which loops back to the “feedback” Pi.
- The “feedback” Pi will collect live data from the Pod’s systems.
- The “control” Pi will be connected to our propulsion and braking system which will loop back to the “feedback” Pi.
- The “feedback” Pi will collect live data from the Pod’s systems. It will be connected back to the ethernet switch which will output the data back to the team laptop via the radio.

SAFETY CHECK:

- Backup battery for control systems if primary fails
- In the event of total power loss, control system will automatically engage brakes

NAVIGATION AND CONTROL COMMUNICATIONS

DESIGN RATIONALE

The general purpose of the design is to maximize CPU usage while keeping a modular design

Factors:

- Two Raspberry Pi submodules
    - One is focused on constant instantaneous feedback
    - The other is focused on controlling the pod
- The ethernet switch is vital in keeping modules separate
    - For example: the switch allows direct connection between the radio and the Arduino Uno.

TESTING AND VALIDATION

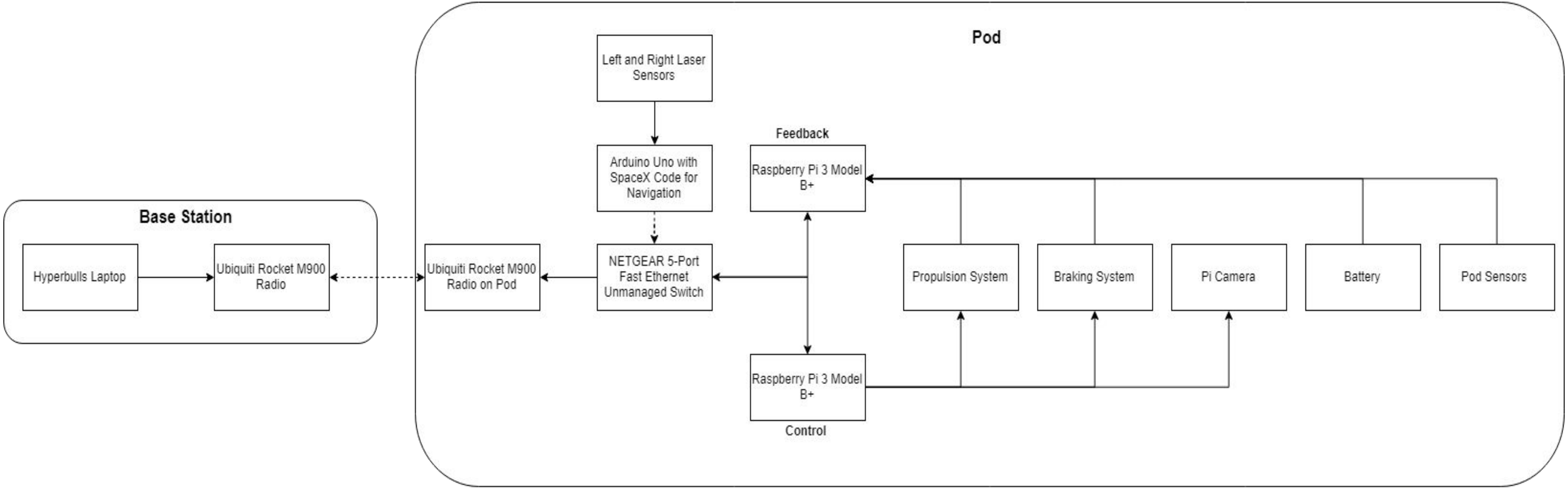
Our initial testing plan is to isolate each subsystem and test them individually

- For example: We could test the “control” Raspberry Pi to start a motor to a desired speed.

As the validity of individual components are verified, they can begin to be tested in tandem.

Logistics of key components will be tested in small scale initially

COMMUNICATIONS DESIGN MOCKUP

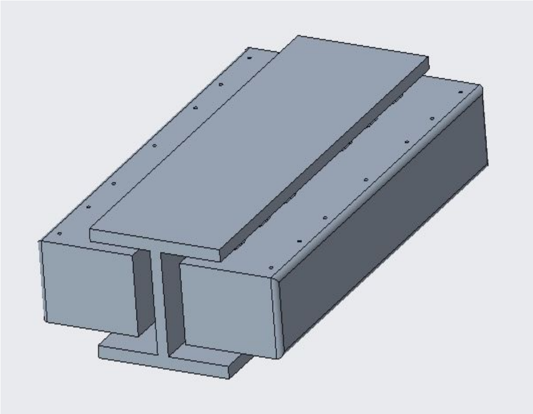


PROPULSION - LINEAR INDUCTION MOTORS

- The pod will include linear induction motors on either side of the the rail as shown

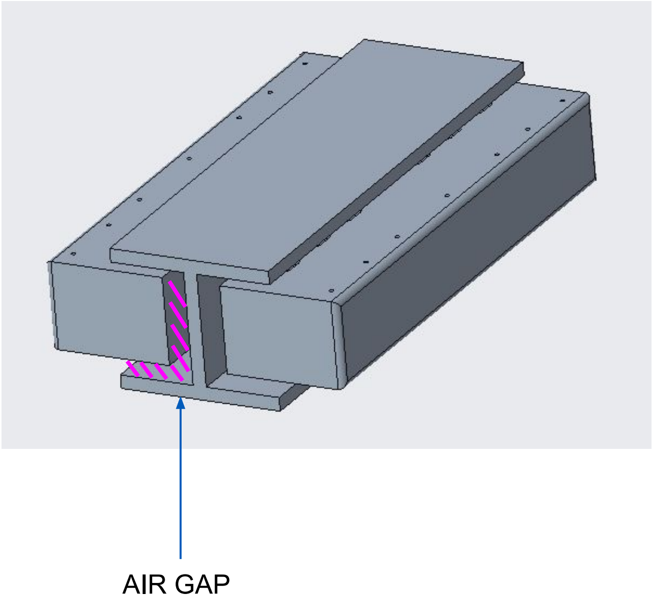
- Three phase alternating current is sent through stators on board pod, generating rotating magnetic field. Utilizing Lorentz forces, rotating magnetic fields created will interact with the conductive aluminum rail acting as the rotor, generating propulsion in the direction of rotation.

- Linear induction motors are self starting, and the linear propulsive force is dependant on the current supplied.



LINEAR INDUCTION - LIMITATIONS

- The speed of the pod depends directly on the coefficient of slip between the stator and rotor. The slip can be minimized by reducing the air gap.
- Eddy current interference creates energy loss - this loss can be mitigated with thin steel sheets embedded between the wound wires.
- Battery can only provide maximum current for ~30 seconds until voltage drop off
- To control heat production, motor will be activated in spurts as opposed to operating continuously



PROPULSION and BRAKING - Testing and Validation

- Testing and verifying the coefficient of friction of the brake pads
- Construct a section of rail of the hyperloop in order to perform the following tests:
    - Test each propulsion method separately to see if actual results match with theoretical predictions
    - Test combinations of propulsion methods
    - Test each braking method separately to see if actual results match with theoretical predictions
    - Test combinations of braking methods

MATERIALS/SAFETY RISKS MITIGATION

POLYCARBONATE OUTER SHELL

- High heat resistance - Melting point ~ 650 degrees Celsius
- Can easily be molded
- Smooth surface allows for minimal increase in drag
- Lightweight
- Relatively inexpensive

ALUMINUM FRAME

- Lightweight
- Non-magnetic
- Supports high loads

NEODYMIUM MAGNETS

- Most common powerful permanent magnets
- Capable of levitating weight of pod
- Operate even at high temperatures

ABSORBED GLASS MAT BATTERIES

- Minimal risk of acid leakage
- Resistance to high/low temperatures
- Suitable for use in a vacuum

ELECTRICAL WIRING

- 0 gauge wiring, of maximum length 4 feet ensures controllable heat production

CARBON FIBER REINFORCED POLYMERS

- If our budget allows, we will explore the use of carbon fiber for the shell and structural components due to its lightweight, rigid properties.

SUMMARY OF SAFETY

SAFETY FEATURE	RISK MITIGATED
Sleek, aerodynamic shape	Reduce horizontal wobbling, eliminate risk of disengagement from the track
Using compressed air	While other gasses may provide higher thrust outputs, air is not flammable, and there is no risk of fuel-based fires.
Addition of failsafe tank	Tank automatically engages if there is power loss, or if there is any other braking malfunction. This ensures that even in the event of a crisis our pod will safely slow down
Anti-lock pulsation braking system	Significantly reduces heat generation, and prevents brake lockup. Automatically engaged in the event of power loss
Utilizing absorbed glass mat batteries	Eliminate risk of acid spillage, even at vacuum pressures
Backup battery	In the event of power loss, backup battery will keep crucial systems online

DESIGN, BUILD, TEST PLAN and TIMELINE

- While we await the preliminary design decision the team will continue working on the design.
- We'll split into smaller groups and begin to work on the packaging and structure of the pod.
- Before our winter break (December 18th) we're aiming to be done with the design and packaging of our propulsion, braking, navigation, and safety systems.
- Upon returning from break (January 28th), we intend to begin building the various systems of the pod, as well as a test track to begin collecting data and iterating our designs.
- After our packaging and structure is designed, we will design the outer shell to fit our requirements while minimizing drag.

FUNDING PLAN

- Funding from the University at Buffalo School of Engineering and Applied Sciences
- Funding from University at Buffalo Honors college department and from the department of Mechanical and Aerospace Engineering.
- Local companies for power system such as batteries, wires, circuits.
- University's 3D printing lab and machine shops for manufacturing and design fabrication of the pod.
- *Budget goal: $15,000*

SOURCES:

https://repository.tudelft.nl/islandora/object/uuid%3Ab91cbd15-3f0b-4491-ae49-fdc01854927c (structures)
http://www.railway-technical.com/archive/vehicle-suspension-systems.pdf (levitation/suspension)
https://www.theverge.com/2016/5/9/11636460/hyperloop-transportation-passive-magnetic-levitation-inductrack-richard-post (levitation/suspension)
https://aip.scitation.org/doi/full/10.1063/1.2162475 (levitation/suspension)
https://www.hbi.ch/fileadmin/downloads/pdf/publikationen/25_Aerodynamics-MAGLEV_Int-Conf-Tunnel-Design-and-Systems-Engineering-2005_Basel.pdf (levitation/suspension)
https://en.wikipedia.org/wiki/Eddy_current_brake (braking)
https://www.princeton.edu/ssp/joseph-henry-project/eddy-currents/eddy_wiki.pdf (braking)
https://cdn.comsol.com/wordpress/2013/02/Step-by-step-guide-for-modeling-heat-generation-in-a-disc-brake.pdf (braking)
https://www.khanacademy.org/science/physics/magnetic-forces-and-magnetic-fields/modal/a/what-are-magnetic-fields (braking)
https://circuitglobe.com/linear-induction-motor.html (propulsion)
https://slideplayer.com/slide/6367759/ (propulsion)
https://link.springer.com/content/pdf/10.1007/BF03325781.pdf (propulsion)
https://ieeexplore-ieee-org.gate.lib.buffalo.edu/document/6523964 (propulsion)
https://ieeexplore-ieee-org.gate.lib.buffalo.edu/document/7295593 (propulsion)
https://www.h2wtech.com/product/linear-induction/LMG-03-325-SSE (propulsion)