STANFORD'S POD PEOPLE

DESIGN BRIEFING 1.0

OUR TEAM

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- STRUCTURAL DESIGN TEAM
  - CELENA STAFF–SUB-TEAM LEAD
  - MEGHANA RAO
- AERODYNAMICS TEAM
  - RONGXIAO “NIC” ZHANG
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- STABILITY & NAVIGATION TEAM
  - CHARLES HALE–SUB-TEAM LEAD
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  - KRISTINE CHEN–SUB-TEAM LEAD
  - NITISH KULKARNI
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- CONSULTING FACULTY
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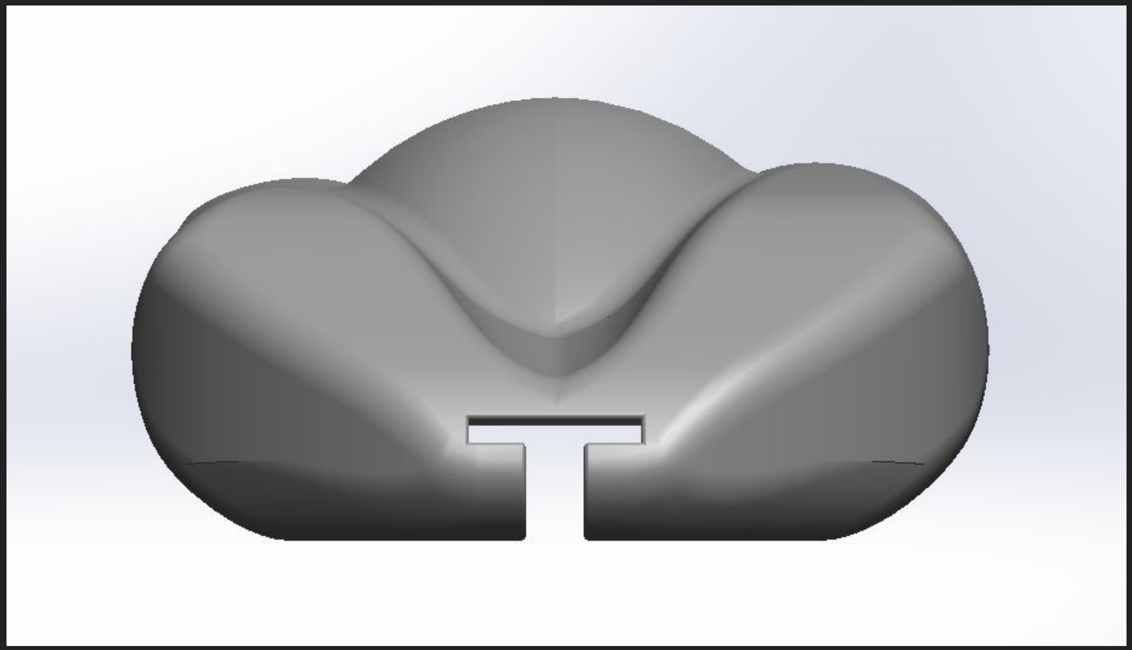
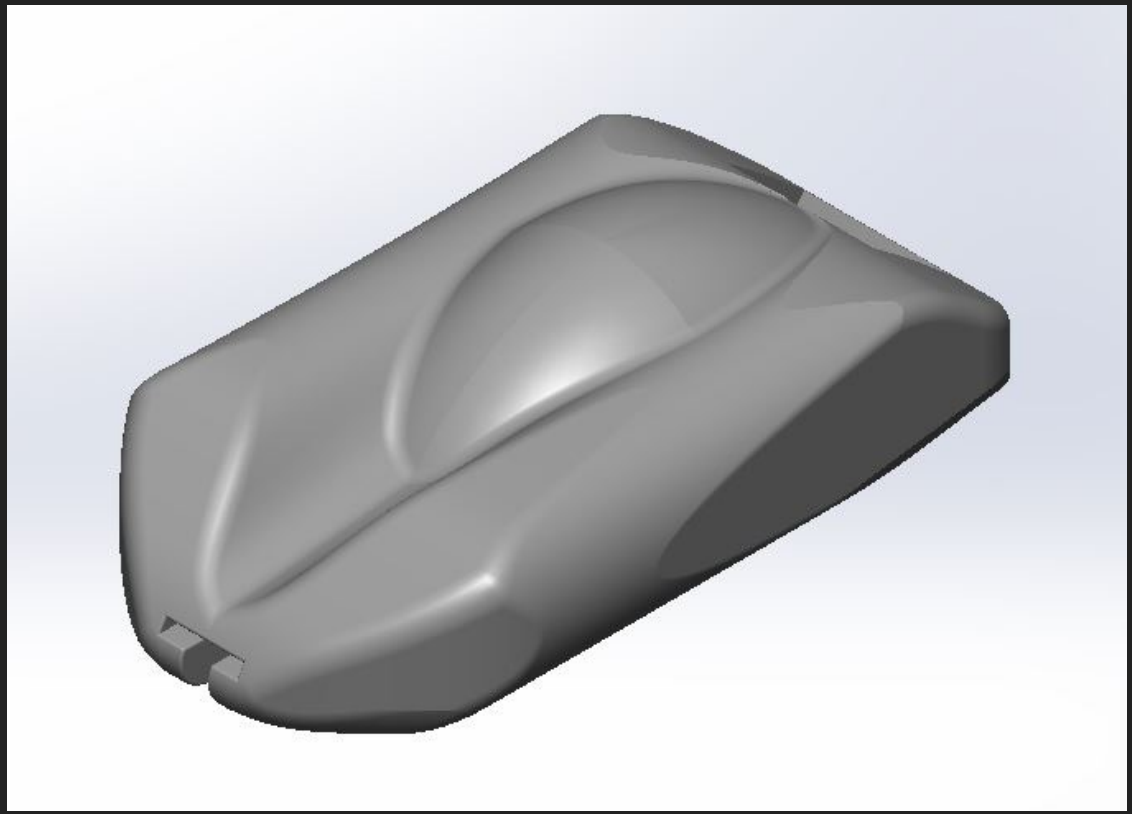
  - PROF. MARK CUTKOSKY
  - PROF. JOHN EATON
  - PROF. PAUL MITIGUY
  - DR. LESTER SU

POD DIMENSIONS

- LENGTH: 59.1″
- WIDTH: 31.75″
- HEIGHT: 16.5″
- STRUCTURAL MASS: 88.1lb
- CARBON FIBER AS STRUCTURAL MATERIAL
  - HEXCEL PREPREG 8552





INITIAL POD DESIGN

POD MASS BY SUBSYSTEM

- LEVITATION
  - High Speed (Halbach Arrays)
    - Test Scale Mass (kg): 347
    - Full Scale Mass (kg): 1853
  - Low Speed (Wheels)
    - Test Scale Mass (kg): 40
    - Full Scale Mass (kg): 40
- STABILITY
  - High Speed (Halbach Arrays)
    - Test Scale Mass (kg): 58
    - Full Scale Mass (kg): 309
  - Low Speed (Mass Spring Damper)
    - Test Scale Mass (kg): 57
    - Full Scale Mass (kg): 57
- NAVIGATION & COMMUNICATION
  - Test Scale Mass (kg): 3
  - Full Scale Mass (kg): 3

POD MASS BY SUBSYSTEM

- BRAKING
  - High Speed Induction
    - Test Scale Mass (kg): N/A
    - Full Scale Mass (kg): 804
  - Low Speed & Emergency (Friction)
    - Test Scale Mass (kg): 40
    - Full Scale Mass (kg): 40
  - Magnet Actuators
    - Test Scale Mass (kg): 0
    - Full Scale Mass (kg): 80
- OTHER
  - Structure
    - Test Scale Mass (kg): 88
    - Full Scale Mass (kg): 700
  - Battery
    - Test Scale Mass (kg): 18
    - Full Scale Mass (kg): 176
  - Compressed Air Tank
    - Test Scale Mass (kg): 8
    - Full Scale Mass (kg): 10

POD MASS - DISCUSSION OF METHODS

- Masses of subsystems determined with Matlab application
- Iterative solver implementing the Banach fixed-point theorem to converge on the matrix of subsystem masses that solves all given conditions
- Special focus on the subsystems whose masses were themselves functions of the mass of the pod
- The code repository will be laid out in the appendices of the final design package, but was not appropriate to include in the preliminary design slide deck

POWER CONSUMPTION

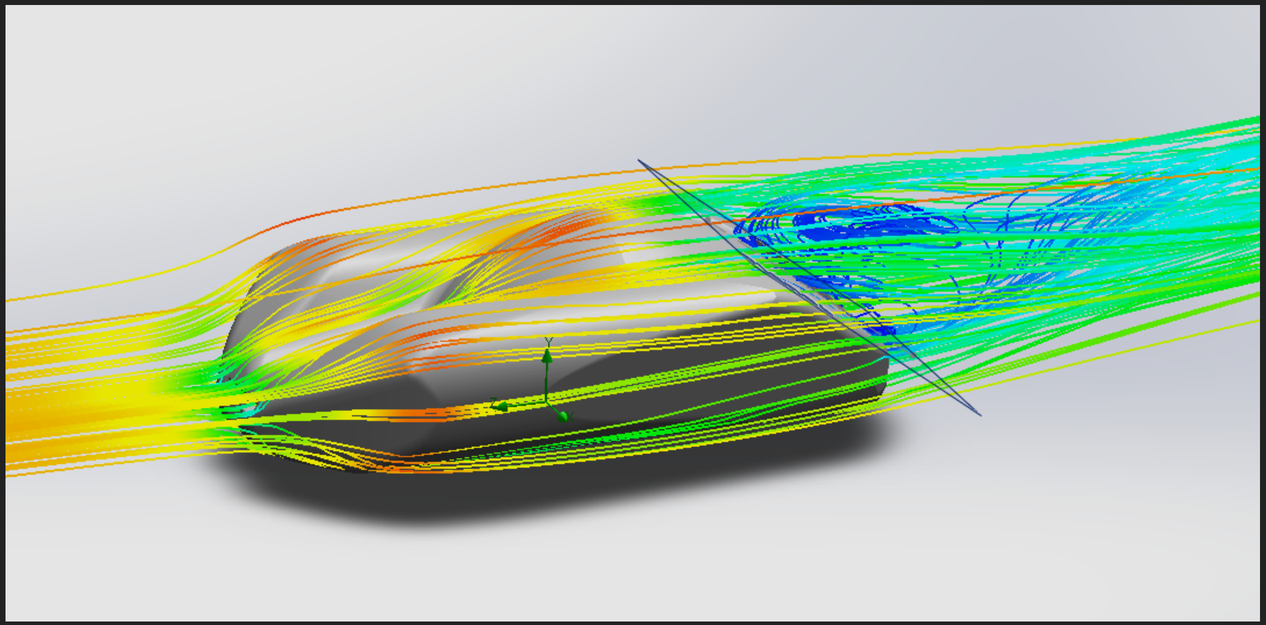
- Major design focus on passive systems
  - Any power usage leads to heat generation, which is difficult to accommodate in a quasi-vacuum
- Besides a small battery bank to provide auxiliary power for electronics and small movements to engage or disengaged the magnetic arrays, only the friction brakes need any significant amount of stored energy
  - Energy for applying friction brakes to tracks provided by compressed gas tank

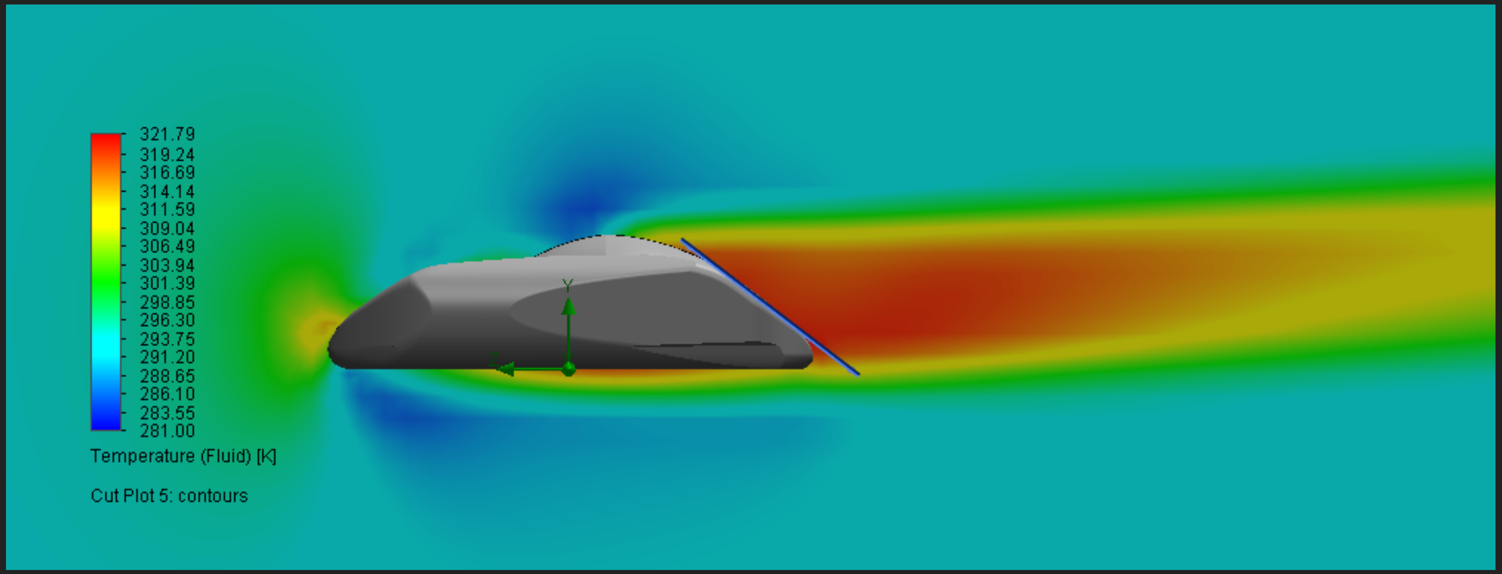
POWER CONSUMPTION BY SUBSYSTEM

- LEVITATION
  - Wheels at low speeds and passive Halbach arrays at high speeds mean levitation requires no substantial power
  - Small auxiliary power may be necessary to set the height of magnet array once at speed
- STABILITY
  - Passive mass-spring-damper system at low speeds when wheels engaged
  - Levitation system naturally stabilizes roll and pitch
  - Lateral stability and yaw disturbances are addressed with Halbach arrays mounted on damped-spring suspension
  - This should be effective, however, future designs may consider an active, powered lateral stability system
- NAVIGATION
  - On board lithium-ion battery bank to power microprocessors and communications devices
- BRAKING
  - Stored compressed air used to provide normal force to actuate brakes
  - Small amount of electricity used to drive motors which move brakes ~2cm from disengaged to engaged position
  - Supplied by onboard lithium-ion battery bank

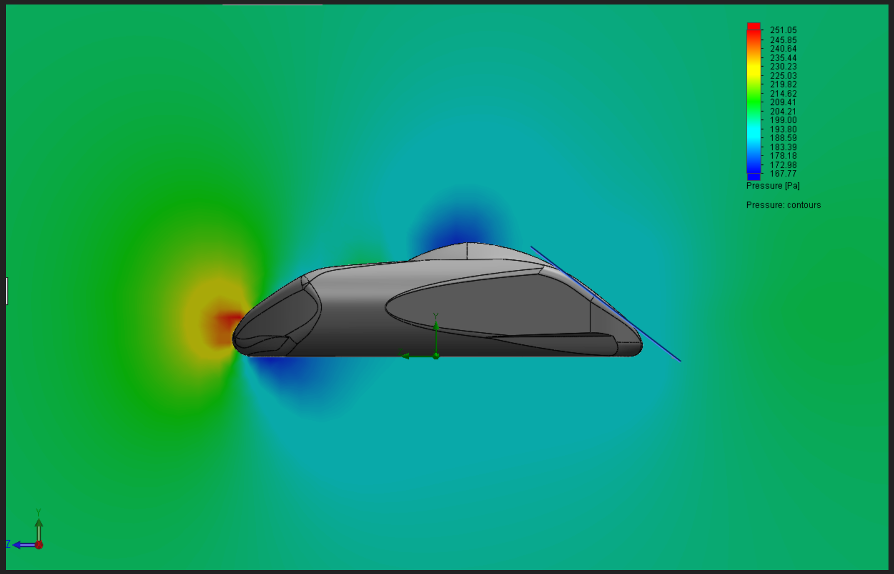
AERODYNAMICS

- Drag Coefficient: ~0.29 @ 200Pa, 293K
- Mach 0.7; Drag: 7.16N
- Max Temperature: 322K
- Max Pressure: 251Pa





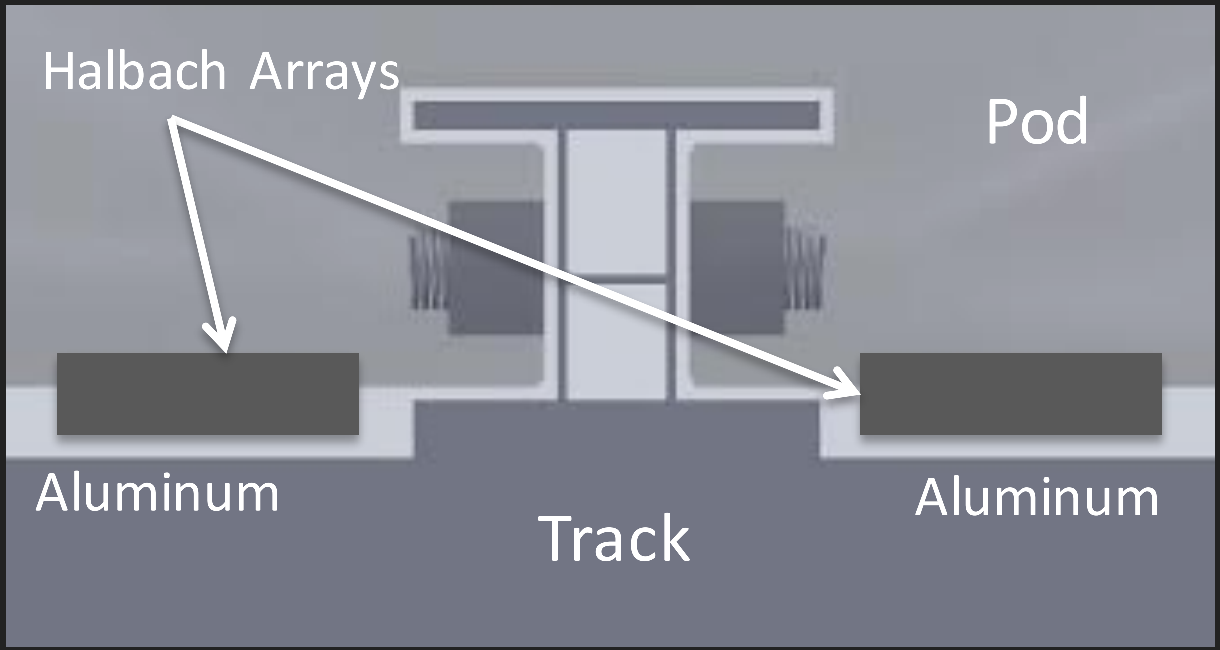
Temperature Field



Pressure Field

LEVITATION

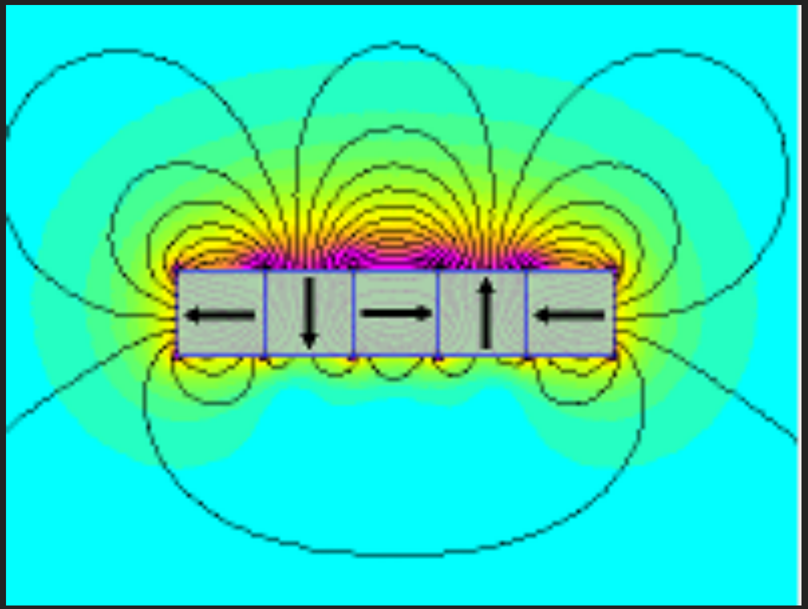
- At low speeds (<40m/s), pods will use wheels
- At high speeds, magnetic levitation will be achieved using Halbach arrays, similar to the "Inductrack" concept
- Using permanent magnets eliminates the need for power



(not to scale)

LEVITATION THEORY

- Rapidly moving array of powerful permanent magnets creates current in conductive aluminum rail
  - Currents create magnetic field opposing that of the Halbach array, generating lift
  - LLNL reported achieving levitation with magnets being as little as 2% of total weight[1]
  - Because we must use a solid aluminum sheet rather than the repeated circuit elements like and ideal Inductrack, we assume lower lift:weight ratio of 8:1
    - Will validate and test this using a spinning aluminum wheel



https://www.kjmagnetics.com/blog.asp?p=halbach-arrays

Halbach array magnet geometry creates magnetic field that is significantly stronger on one side

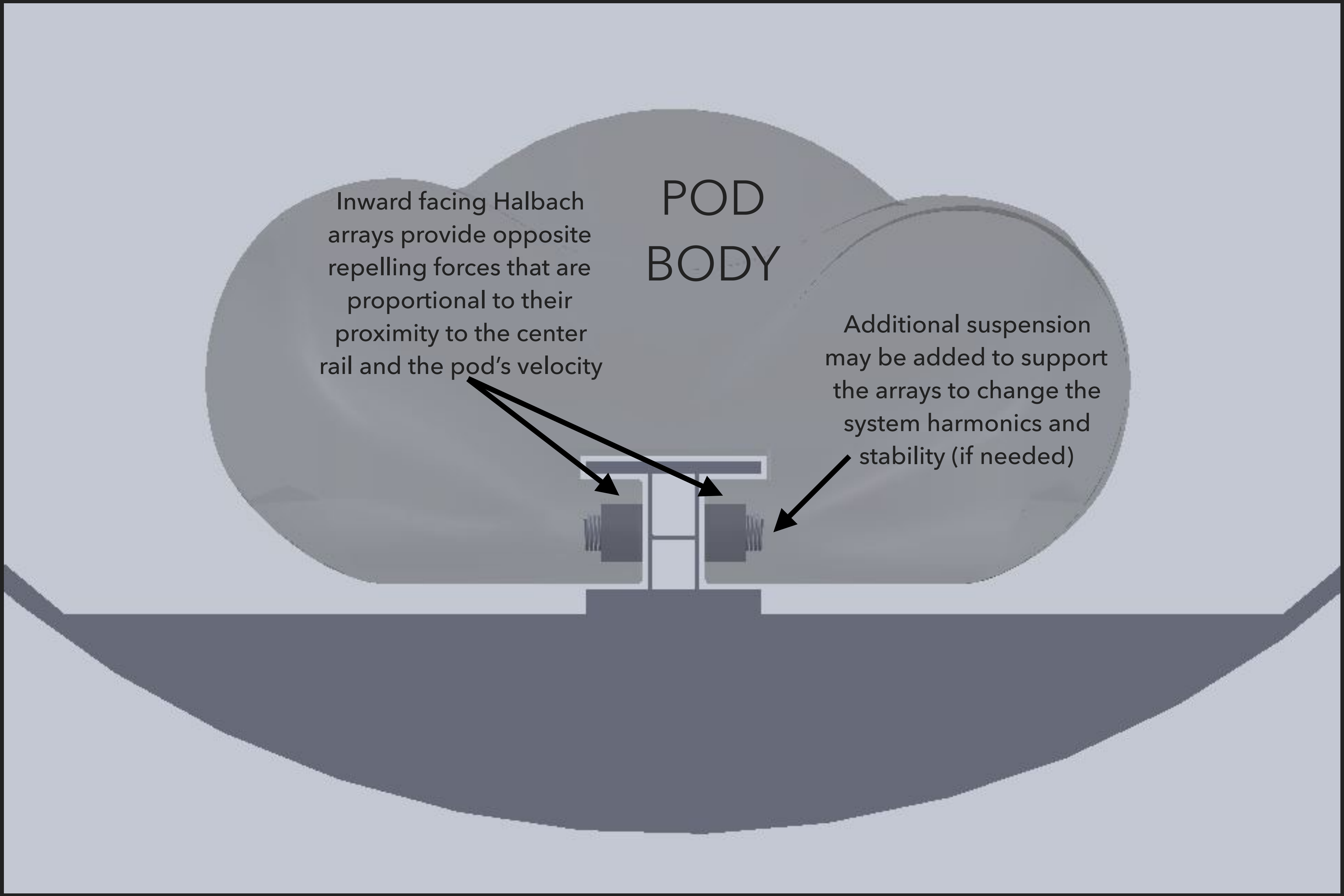
ADDITIONAL CONSIDERATIONS

- LLNL achieved gap height of up to 25mm at just 15m/s
  - This will likely be larger than is necessary for our purposes, but gives significantly more clearance than air bearings, and comparable to ArxPax
  - Gap height was a concern with commercial air bearings because of track roughness tolerances
- Effectiveness of magnetic levitation scales directly with velocity, so our higher speed should make up for the lack of a magnetic coil track
- We may mount the Halbach arrays on a linear actuator
  - This would enable us to retract the magnets and use wheels when braking is required
  - Also allows finer control of height and pitch of pod body

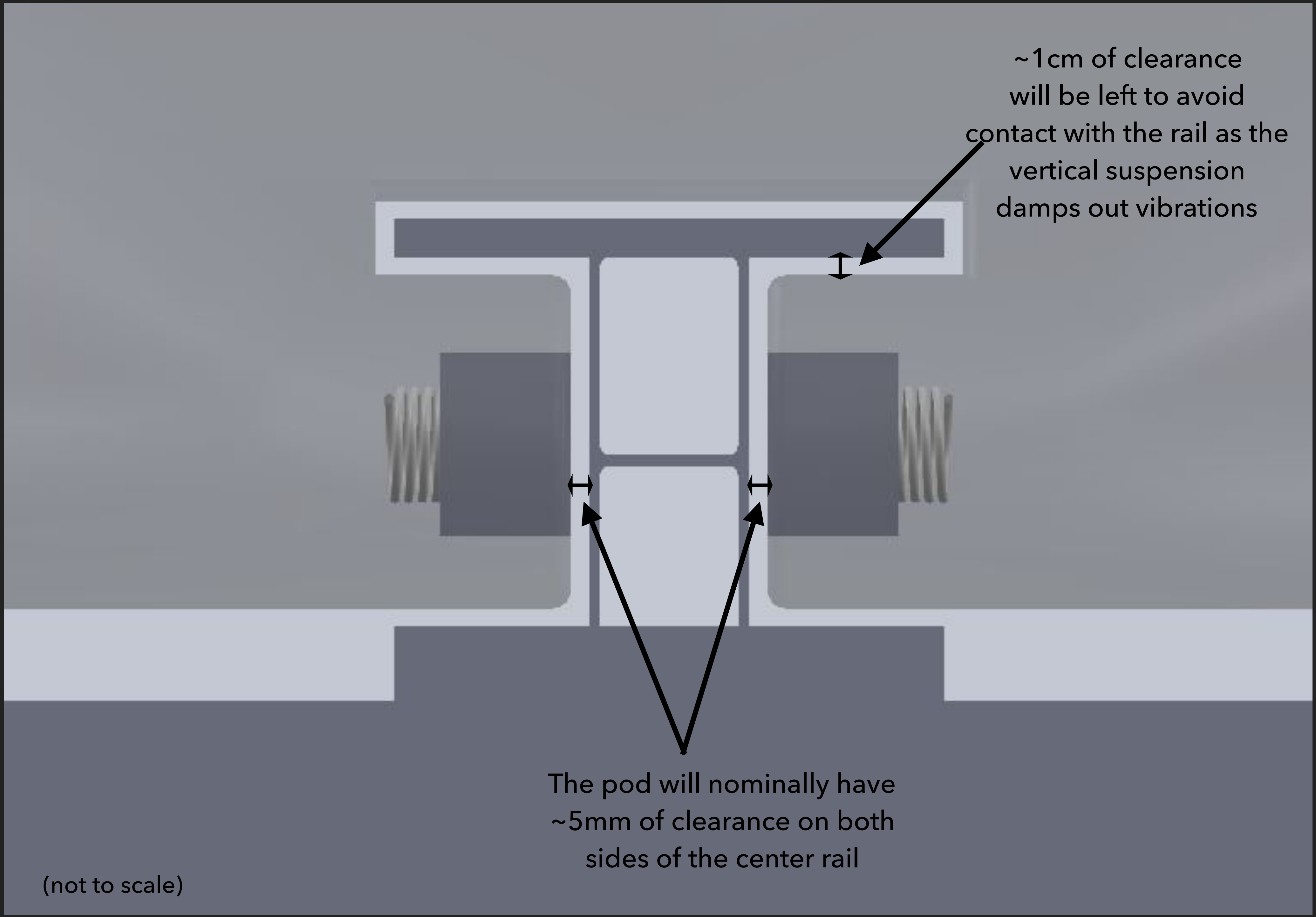
STABILITY

- At lower speeds, there will be wheels with spring suspension rolling along the T-bar, hugging the bottom of the overhang and the sides of the T
- Possibility of electromagnetic active control system to control yaw, roll, and height oscillations
  - Works in same manner as levitation system, just with adjustable electromagnets rather than permanent magnets
  - ArxPax may be better suited for this purpose, since electromagnets will not work at lower velocity

OVERVIEW OF SYSTEM

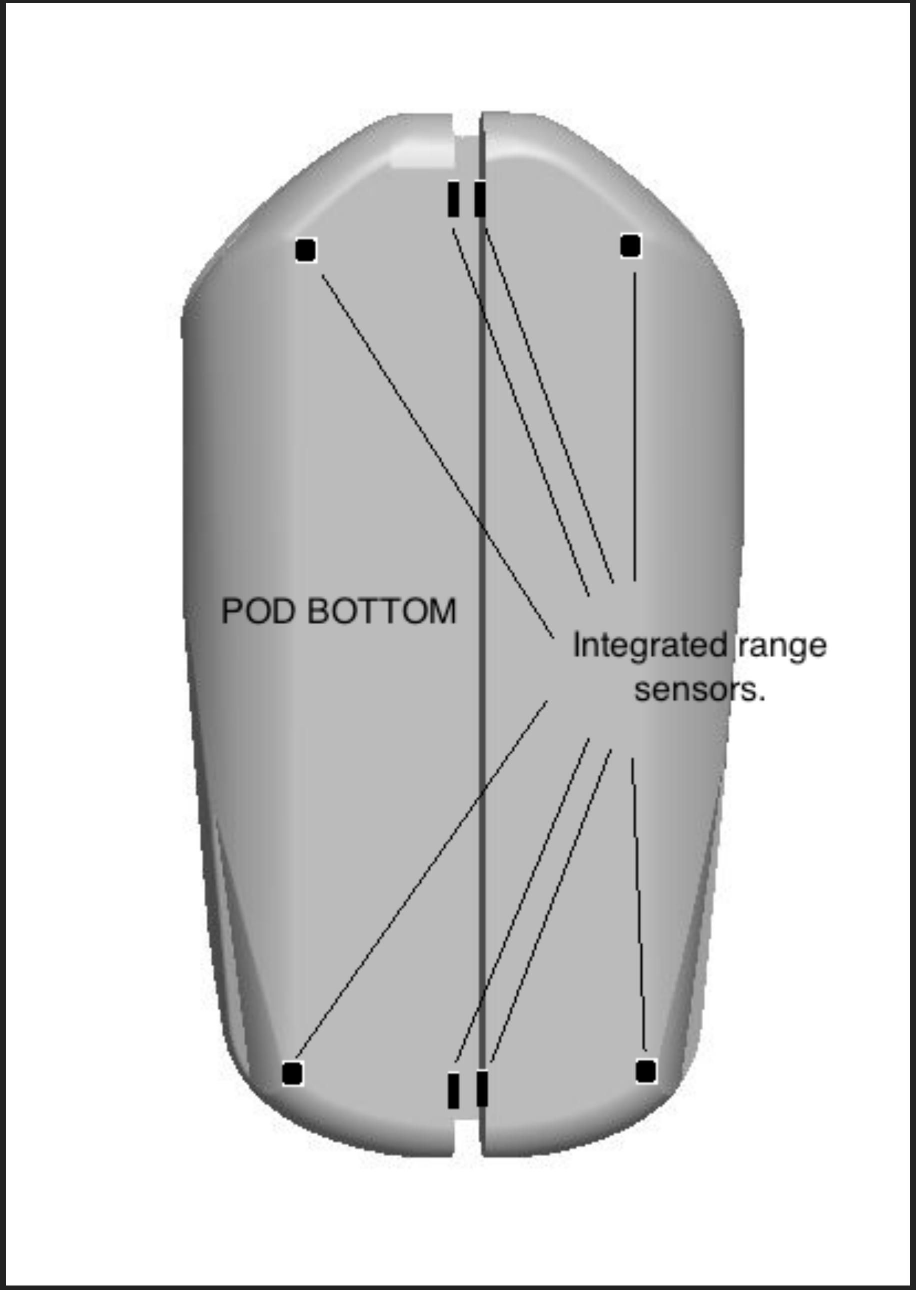


DESCRIPTION OF SYSTEM



NAVIGATION SYSTEM OVERVIEW

- The system will have a large set of integrated range sensors to give an idea of pod's height, roll, pitch, and yaw relative to the ground and central rail
- Pod will use a micro-controller and LED emitter to detect the passing strips of tape, and will use this, along with accelerometer information, to determine its approximate velocity

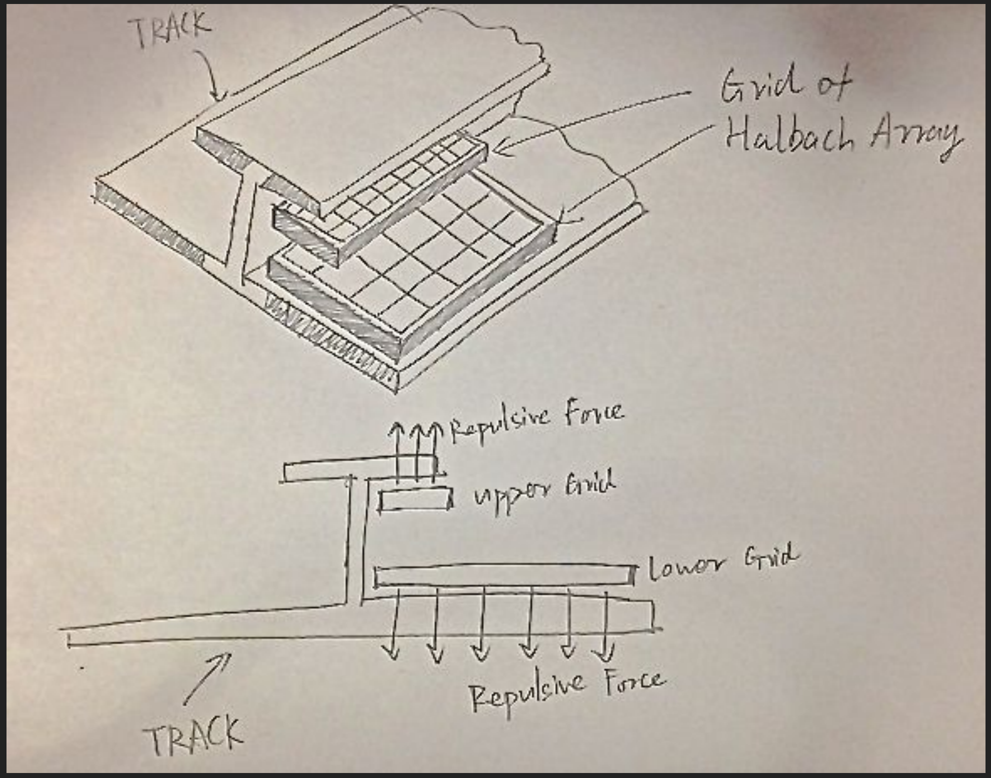


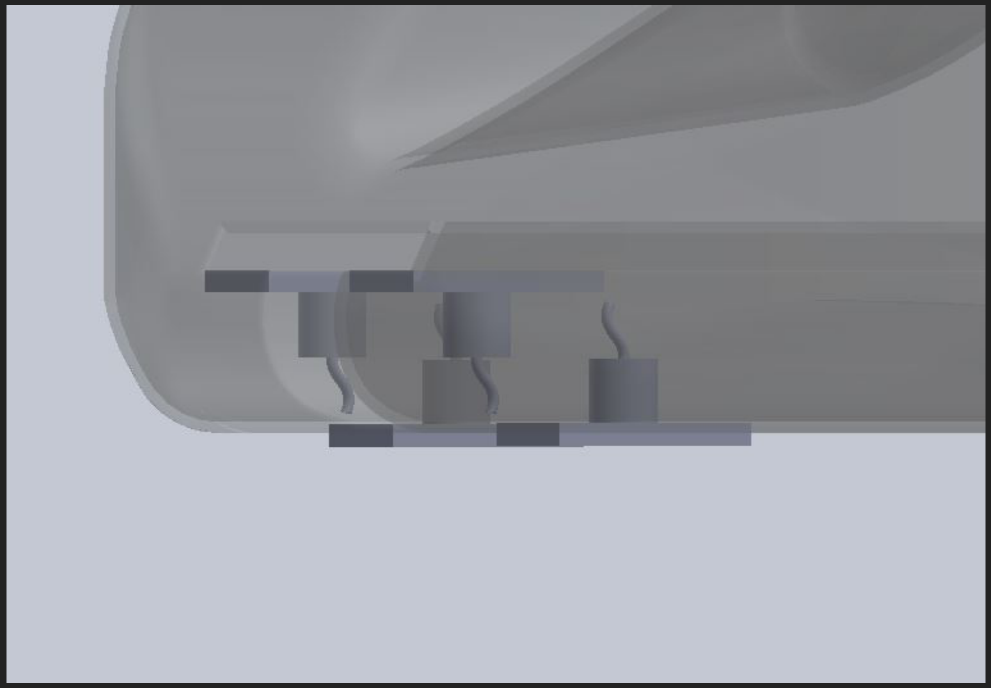
USES AND TACTICS

- Both pod designs will use this information in realtime, along with sensor readings from every other major subsystem to determine if there is need for an emergency stop, and will resort to its range of braking options to produce the appropriate response
- In full design, this sensor information will be integrated into active control systems (electromagnets faced towards the ground and center rail)
- However, current test pod only has passive stability systems and as such navigation will only be required in the case that an emergency stop is needed

BRAKING

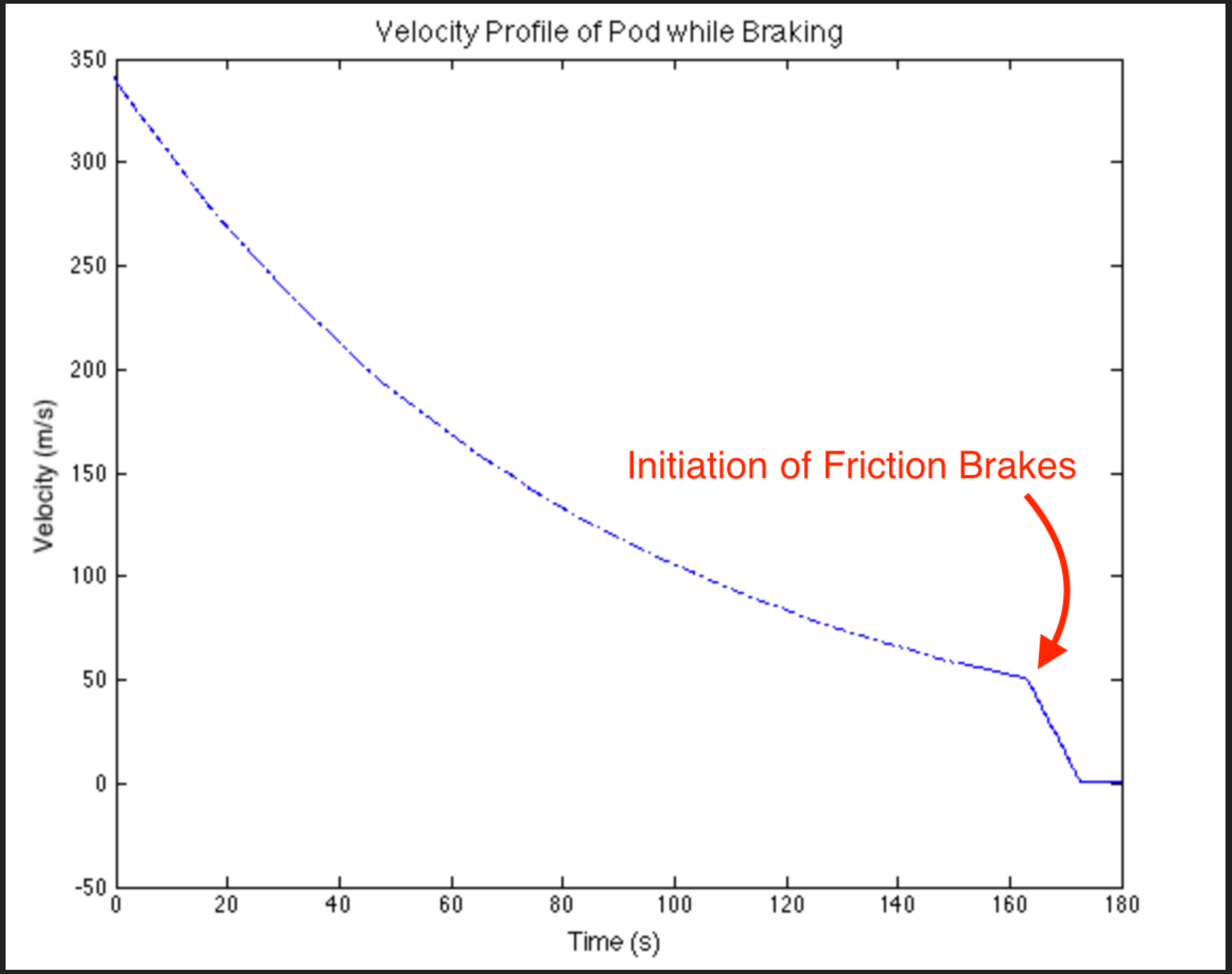
- High speed braking will use induction braking
  - No power consumption or heat dissipation within pod
  - Kinetic energy of pod dissipated as heat in the track via induced eddy currents
  - Braking force varies inversely with velocity so ineffective at low speeds
- Low speed braking (<50m/s) will use friction brakes
  - Heat management is reasonable at low speeds and the short time to finish the braking process
- Emergency Braking
  - Friction brake system over-designed so that in emergencies it can be applied at full speed





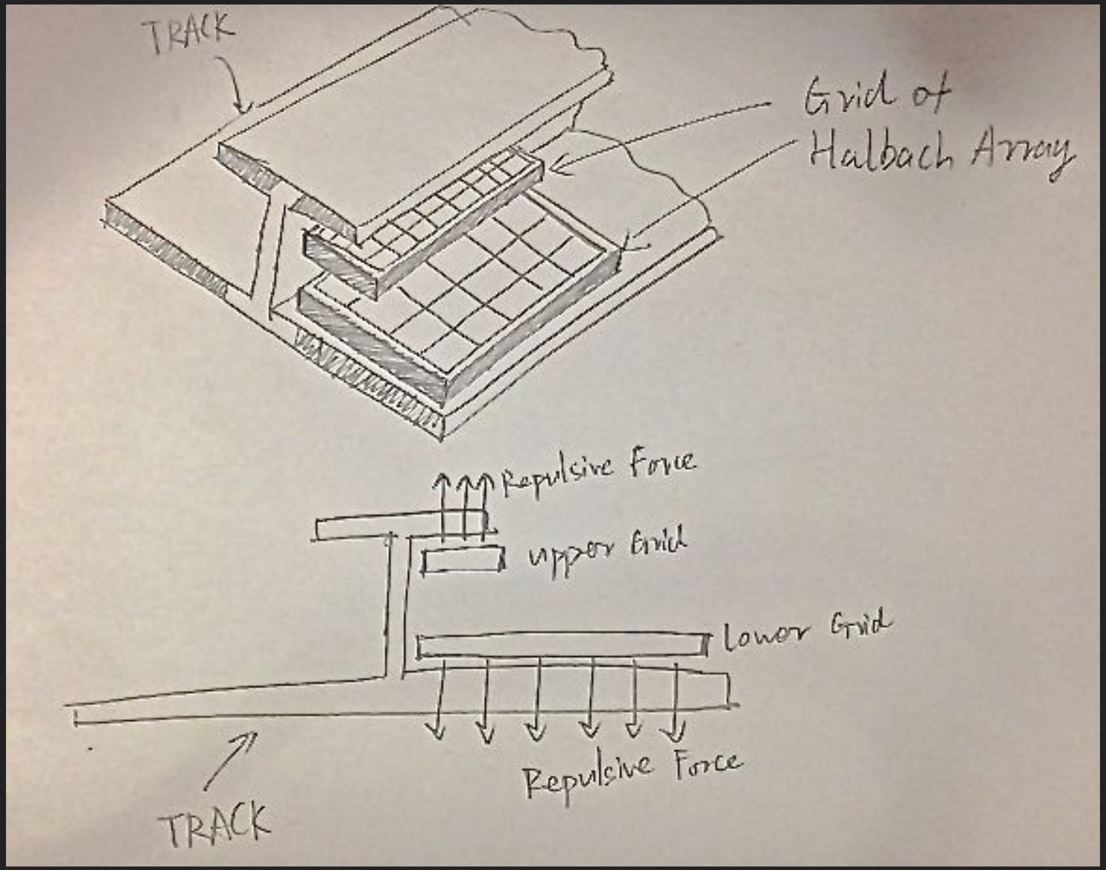
INDUCTION BRAKING CALCULATIONS

- Braking force is a function of the magnet size and the velocity of the pod
- Stopping time depends on braking force and the mass of the pod
- Numerical solver used to converge on the necessary mass of magnet to stop within a given time



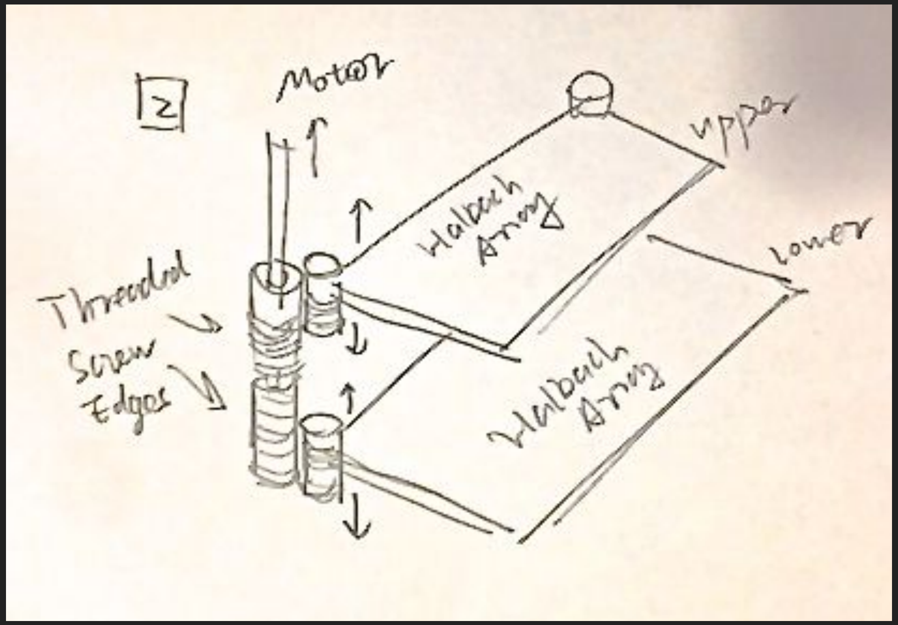
INDUCTION BRAKING – STRUCTURAL DESIGN

- The induction brakes will be mounted over the main track and beneath the T-bar
- Opposing orientations necessary because magnets generate lift, which must be balanced to maintain proximity to track
- Brake positioning accomplished with either an electronic linear actuator or a hydraulic system



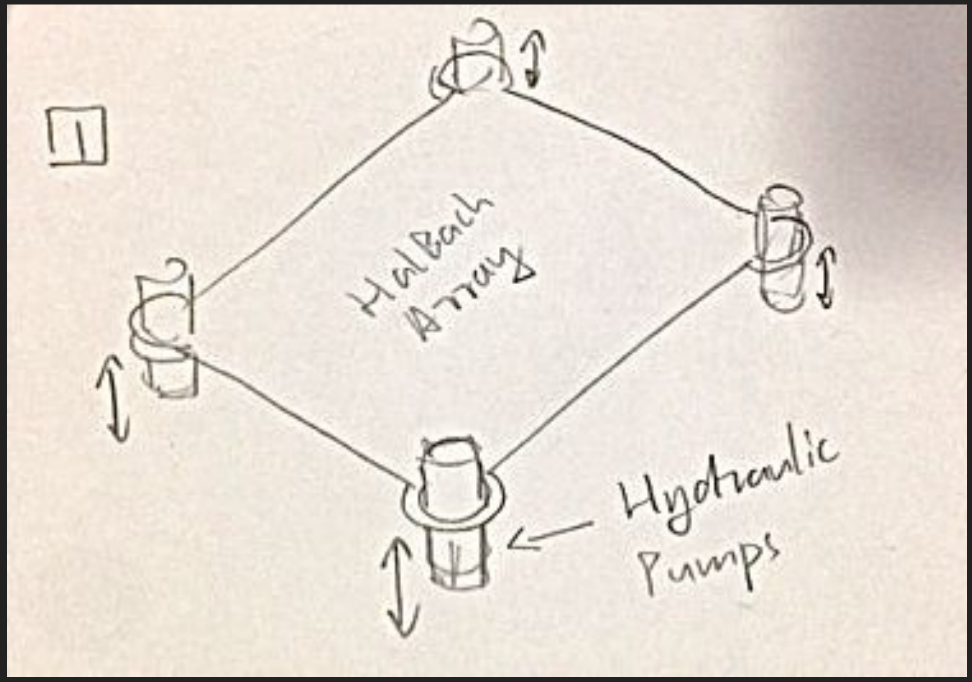
INDUCTION BRAKING – STRUCTURAL CONCEPT 1

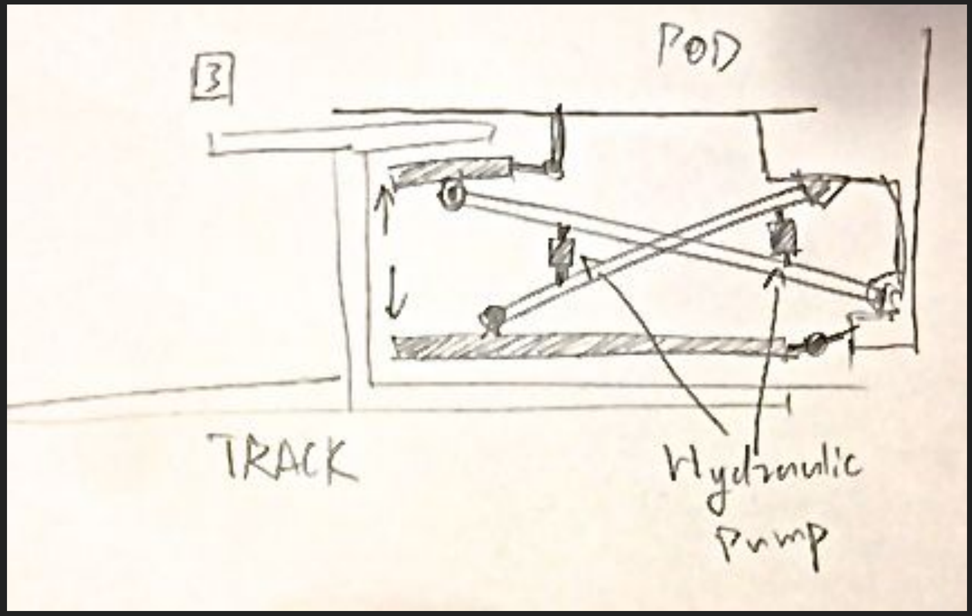
- LINEAR ACTUATOR SYSTEM
  - Brakes will be braced against aluminum track and T-bar to increase normal force
  - Energy necessary to move brakes approximately 2cm from disengaged to engaged will be minimal



INDUCTION BRAKING – STRUCTURAL CONCEPT 2

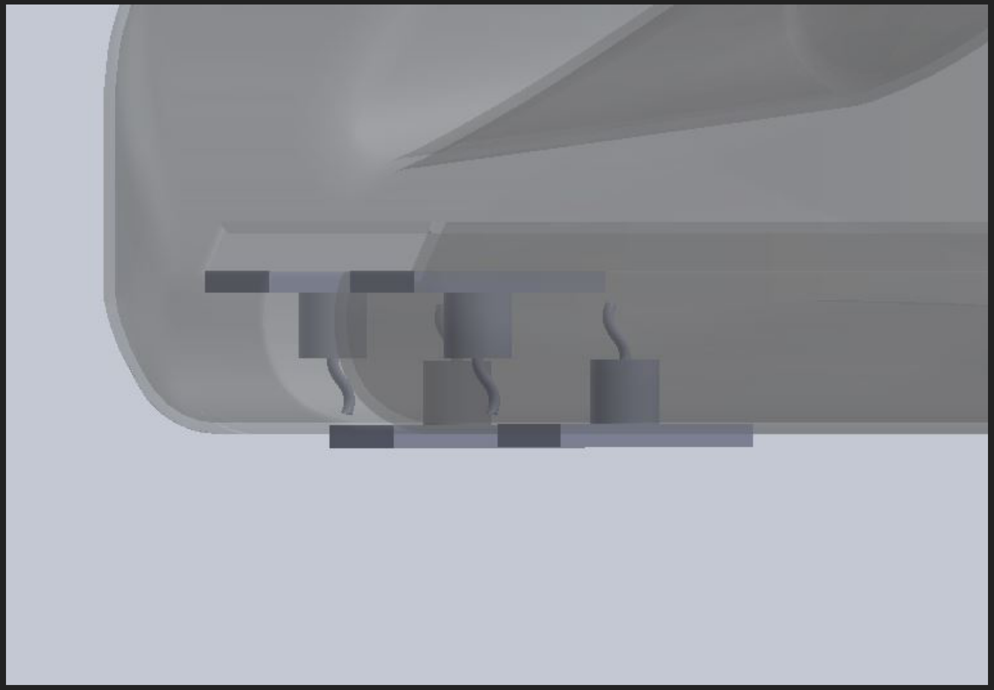
- HYDRAULIC SYSTEM
  - Brakes will be braced against aluminum track and T-bar to increase normal force
  - Wouldn't need to store electrical energy for linear actuator but would need pressure vessel to power hydraulics





FRICTION BRAKING

- LAYOUT
  - Brake pads press up on underside of T-bar and down on main track so large normal forces are opposing
- ACTUATION
  - High normal forces generated by applying stored high pressure air to a piston which drives brake pad onto track
  - Tank comparable to a scuba tank will provide sufficient pressure to generate the necessary normal forces



STORED ENERGY

- Rechargeable lithium-ion batteries (~12V, ~1200Watt*hr)
  - Navigation and communication
  - Moving induction braking array from disengaged to engaged position (about 2cm)
  - Moving levitation array to appropriate ride height once at speed (on the order of millimeters)
- Compressed air
  - Friction braking - supplies pressure to deliver necessary normal force
    - A scuba tank, typically 3000psi, will provide generous air pressure and capacity to actuate the pistons and force the brake pads onto the track
    - Sufficient compressed air to apply friction brakes in an emergency situation at a higher normal force to quickly stop pod

SAFETY FEATURES

- Safety Bladder
  - At the tube operating pressure of 0.02psi, water boils at room temperature, therefore pressure must be maintained for passengers in case of external wall failure
  - Lines inside of pod and acts like a large space suit in case of breach in external structure
- Reinforced Passenger Zone
  - Similar to the roll cage of a car but also with high thermal resistance
  - In the event of the tube rapidly re-pressurizing, the skin temperature of the pod could rise dramatically, insulation of passenger zone can help keep temperatures survivable
- Emergency Braking
  - Friction brake system over-designed so that in case of emergency the brakes can be applied at full speed
  - Will likely be destructive to track and brake pads, but an emergency feature that could save lives if the pod needs to stop rapidly
  - The air supply valve will be on a deadman's switch so that the brakes will automatically deploy in the event of a complete power failure

REFERENCES

1. https://e-reports-ext.llnl.gov/pdf/237852.pdf
2. http://mafija.fmf.uni-lj.si/seminar/files/2007_2008/BRAKING_MAGNETIC.pdf
3. http://www.fem.unicamp.br/~phoenics/EM974/PROJETOS/PROJETOS%202%20SEM-11/TURMA%20A/G7%20OK/artigo_referencia.pdf
4. http://www.a-sp.org/~/media/Files/ASP/Lightweight%20Programs/Mass%20Compounding%20Final%20Report.pdf