UC Santa Barbara

Preliminary Design Briefing

UC SANTA BARBARA
engineering

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TEAM

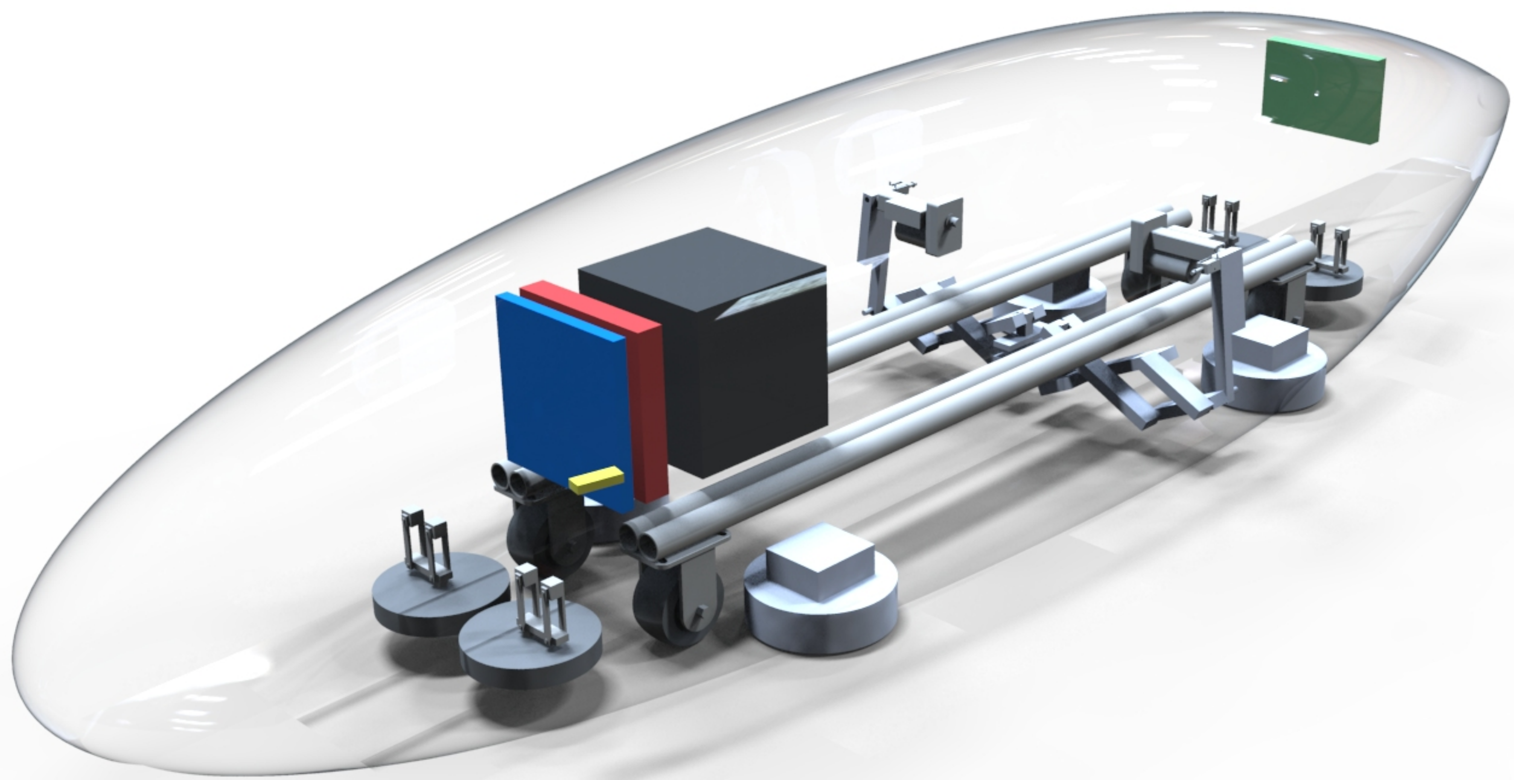
TEAM

- 20 senior engineering undergraduates mentored by faculty members, grad students and industry advisors
- Have already begun building and prototyping
- **Plan to present at Design Weekend and build a complete pod for National Competition Weekend**
- Estimated cost to complete design: $30K
- Funding/resources already obtained:
  - $15K from Ingersoll Rand, Raytheon, private donors
  - $2K in university travel grants
  - Electronics donated by NXP Semiconductors
- Remaining ~$15K to be raised from additional industry partners and a team fundraising event

TEAM

- **Structures & Integration**: Trevor Fritz, Kyle Collett, Lucas Dewey, Viraj Khatri, Nathan Ransom
  - Faculty Advisor: Professor Tyler Susko, PhD, Mechanical Engineering, MIT
  - Graduate Student Advisor: Petros Serbana
- **Aerodynamics & Levitation**: Sarah Conley, Dasun Hemachandra, Annie Kim, Kristine Lai, Daniel Vong
  - Faculty Advisor: Dr Greg Dahlen, PhD, Mechanical Engineering, UCSB
  - Graduate Student Advisor: Brian Gibson
- **Electrical Engineering**: Chris Johnson, Mary Alice Callaghan, Juan Castillo, Elena Georgieva, Terrence Tran
  - Faculty Advisor: Professor Ilan Ben-Yaacov, PhD, Electrical and Computer Engineering (ECE), UCSB
  - Power Electronics Advisor: Dr. Jim Honea, PhD, ECE, UCSB
  - Graduate Student Advisor: Stephanie Johnson
- **Computer Engineering**: Celeste Bean, Connor Buckland, Ben Hartl, Cameron McCarthy, Connor Mulcahey
  - Faculty Advisor: Dr John Johnson, PhD, ECE, UCSB
  - Graduate Student Advisor: Will Miller

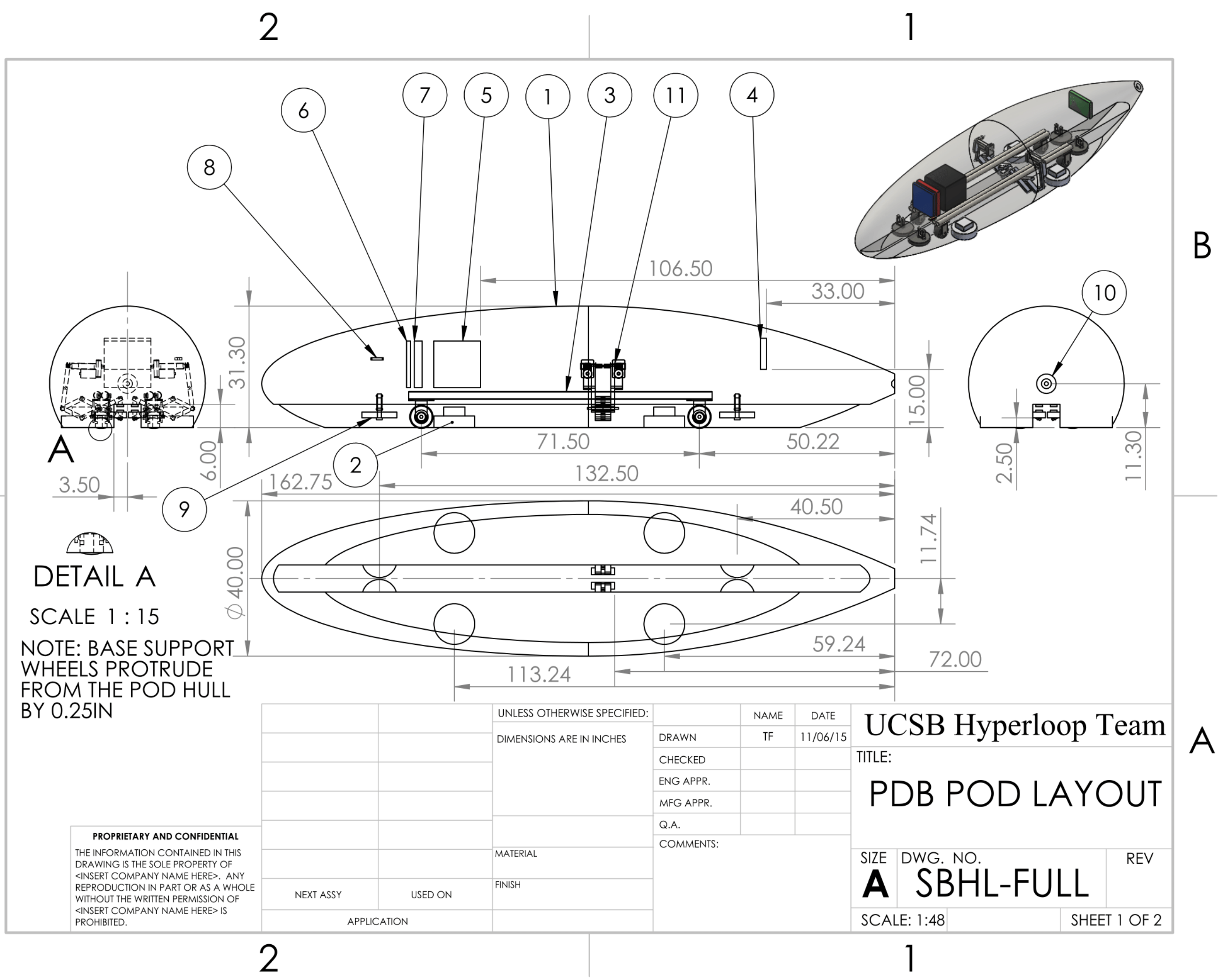
POD OVERVIEW



POD OVERVIEW

- Outer **shell** made of ABS Plastic: 13.5’ long by 31.3” tall by 40” wide
  - 0.15 drag coefficient from simulations
- **Frame** made of evenly spaced, low carbon steel ribs
  - Ribs will be welded together with steel tubing contours
- Pod **levitation** via four ArxPax hover engines
  - Powered by Lithium Polymer batteries
- **Backup wheel** assembly
  - Safety measure for levitation failure
  - Transport pod when not on a conducting surface
  - Wheels protrude 0.25” below hover engines
    - Constrains minimum hover height to 0.25”
- **Propulsion** via SpaceX pusher
  - Calculations use acceleration of 2.4 g for 560 ft to reach 200 mph
- Caliper **braking system** around center I-beam
- **Stabilizing centering wheels** around center I-beam
- On-board electronics include **telemetry**, **controls**, and **communications systems**

POD DIMENSIONS



Legend

ITEM #	PART NO.	DESCRIPTION	QTY
1	SBHL-A-S	Pod Shell	1
2	SBHL-L-E	ArxPax Engine	4
3	SBHL-S-WB	Wheel Base Assy.	2
4	SBHL-C-NAP	Network Access Panel	1
5	SBHL-E-B	Battery	1
6	SBHL-C-PCB	PCB	1
7	SBHL-E-ECB	Electronics Control Board	1
8	SBHL-FDR	Flight Data Recorder	1
9	SBHL-S-SW	Beam Stabilization Wheel Assy.	2
10	SBHL-S-PI	Pusher Interface	1
11	SBHL-S-B	Braking Assy.	2

POD DIMENSIONS

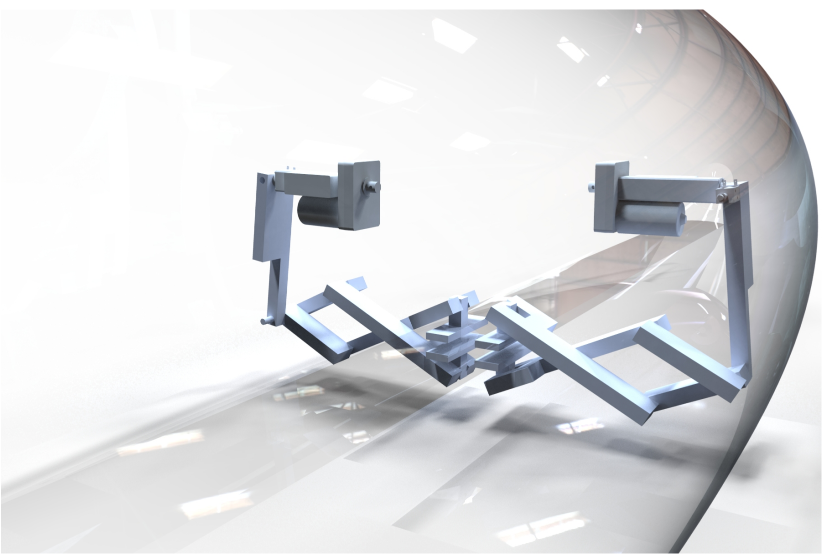
specific subsystems

Braking assembly:

- 7” wide by 6” tall cut at bottom center of the shell allows space for the stabilization assembly and the I-beam stabilization assembly
- Located at aft

Loading/backup wheels:

- Loading/backup wheel system will be positioned close to the fore and aft
- Protrude 0.25” below the maglev engines
- Supports the pod during transit and in the event of a power failure

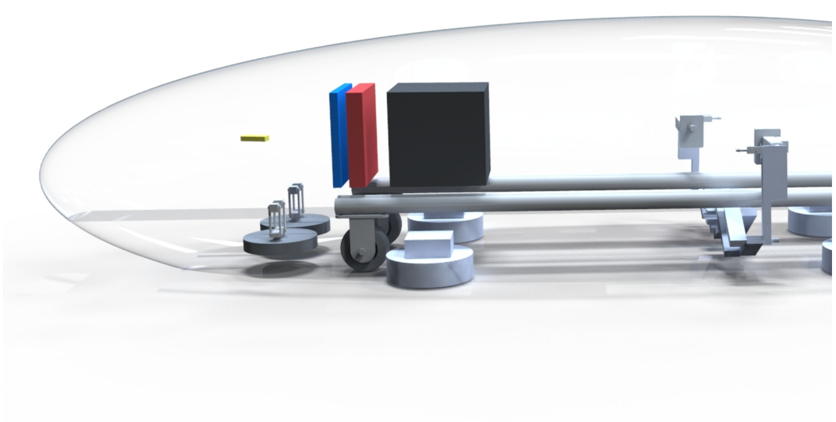


POD DIMENSIONS

specific subsystems

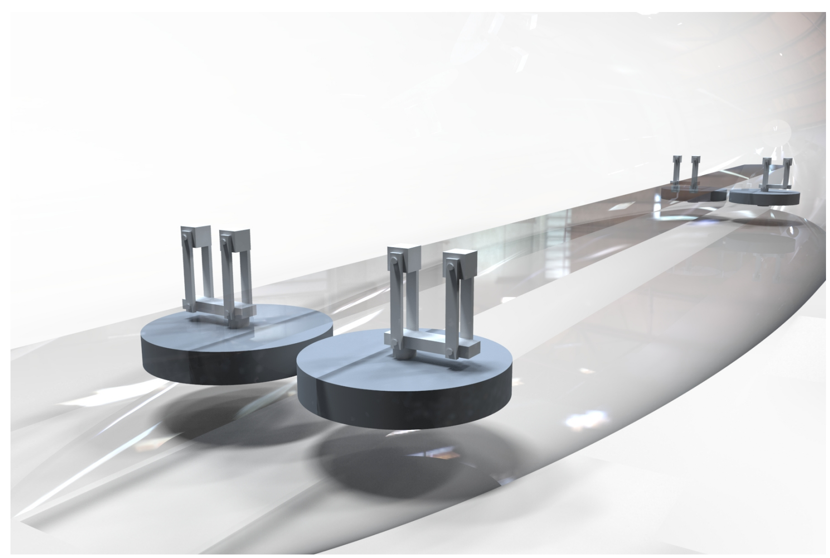
Battery:

- The battery is positioned in the front to allow for stable flight



I-Beam wheels:

- The I-beam centering wheels will be placed 2.5”-3” above the track close to the fore and aft of the pod (2 assemblies)



POD MASS

subsystem materials

Part Type	Materials
Shell	ABS Plastic
Frame	Low - Medium Carbon Steel
Brakes	Low - Medium Carbon Steel (for linkage system)
Engines	Aluminum
Wheel Base	Low - Medium Carbon Steel
Center Support	Medium – High Carbon Steel
Battery	Lithium Polymer

POD MASS

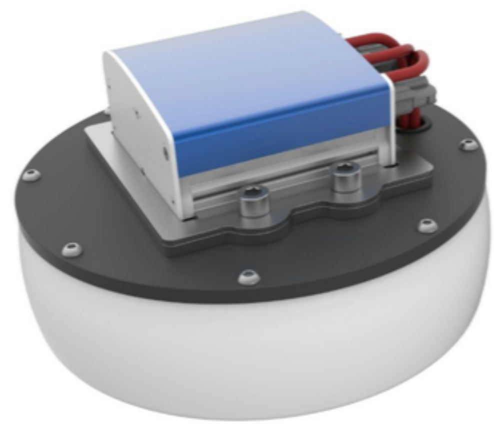
subsystem weight

Subsystem	Weight
Shell	~30 lbs
Frame	~140 lbs
Brakes	~40 lbs
Engines	~60 lbs
Wheel Base Support	~75 lbs
Center Support	~50 lbs
Battery	~40 lbs
Other Electronics	~5 lbs
Total Mass	**~440 lbs**

LEVITATION

mag-lev advantages

- System utilizes Arx Pax's magnetic levitation hover engines
- Best chance of success in the competition while still adhering to the future scalability of the Hyperloop
- Needs to hover at least 0.25" past the bottom of the hover engines
  - Backup wheel system protrudes 0.25" from the bottom of the pod
  - Needs enough clearance to avoid potential inconsistencies in the track
  - Needs to handle turbulence at high speeds



Arx Pax HE3.0 Hover Engine

LEVITATION

mag-lev pros & cons

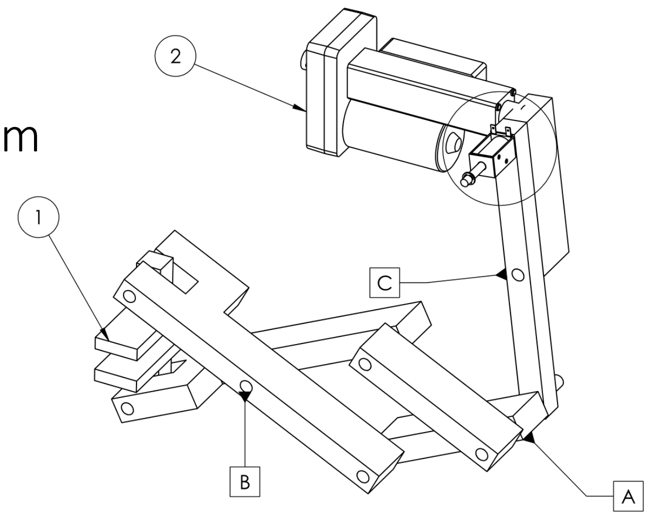
Advantages	Limitations

• Near frictionless
• Ability to operate at high speeds and in low-pressure environments
• Eliminates need for heavy compressed air tanks required for air bearing systems → reducing overall pod mass
• Electrically controlled via Accelerated System's high power motor controller
	• Pod mass
	  • Limited by the lift capabilities of the Arx Pax engines
	  • Four-engine system supports ~445 lbs at the minimum hover height of 0.25”
	• Power Consumption
	  • More power consumption from the engines → more required battery capacity → increased pod mass

BRAKING

primary braking

- Caliper braking system
  - Friction-based system pinching the center I-beam
- Linear Actuator (2) interacts with attached spring at location A
  - Controlled braking via Pulse Width Modulation
  - Not braking
    - Actuator arms extends
    - Releases spring force
    - Relieves caliper brakes
  - Braking
    - Actuator arm contracts
    - Opposes spring force
    - Applies caliper brakes



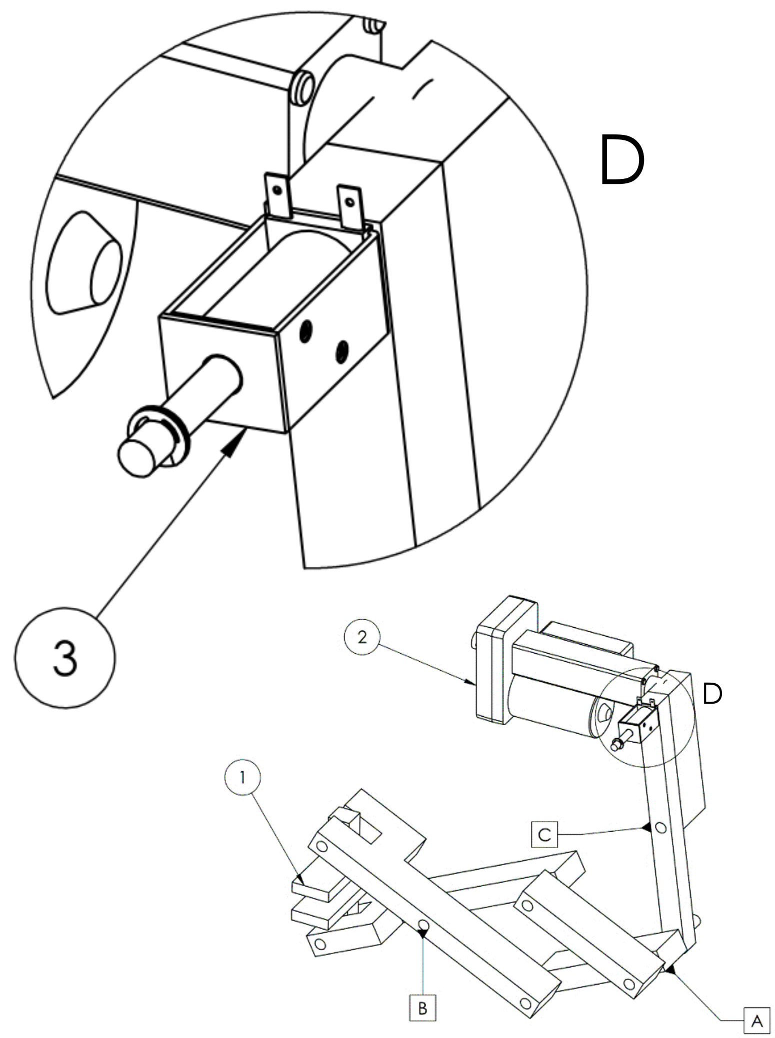
Legend

1	Pads touching I-beam
2	Actuator
A	Tension spring attached here
B	Axis fixed to frame
C	Axis fixed to frame

BRAKING

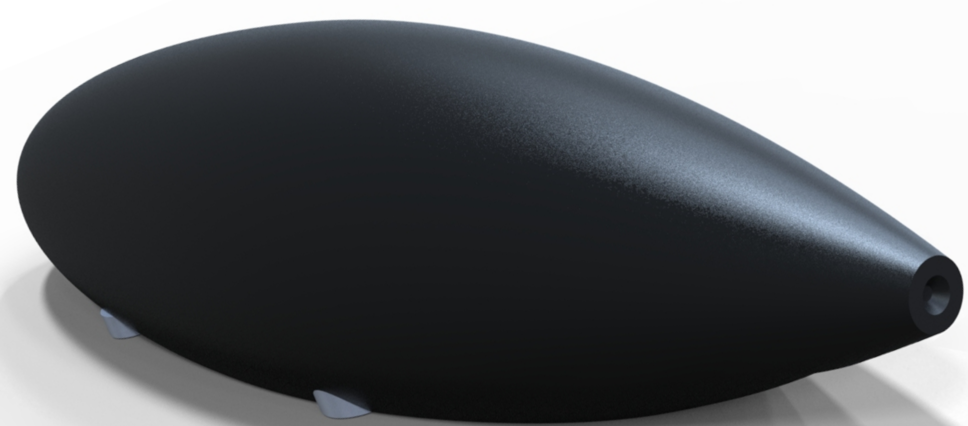
fail-safe condition

- Linear solenoid (3) links actuator and caliper braking system
  - When power is applied, system is connected
    - Controllable braking via actuator
  - If power is lost, linear solenoid pin retracts
    - Disconnects actuator from caliper braking system
    - Spring force then applies emergency braking



PROPULSION

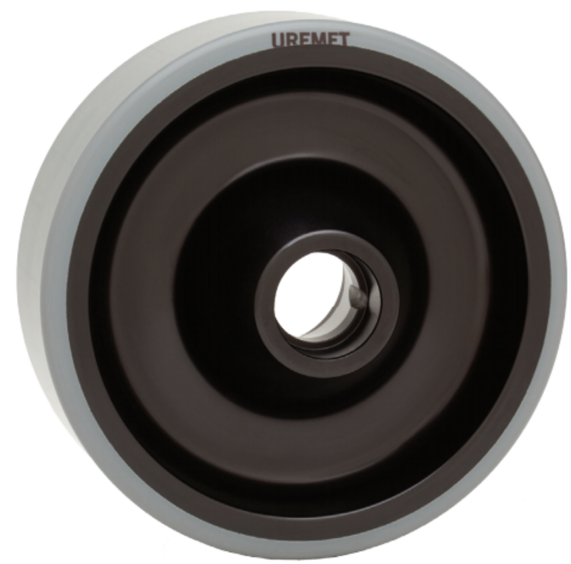
- Propulsion will come from the SpaceX pusher
- The interface to the pusher is located at the back center of the pod
  - 11” above the base
- Max acceleration of 2.4 g for 560 ft to reach 200 mph
  - Begin braking immediately after acceleration phase



STABILITY

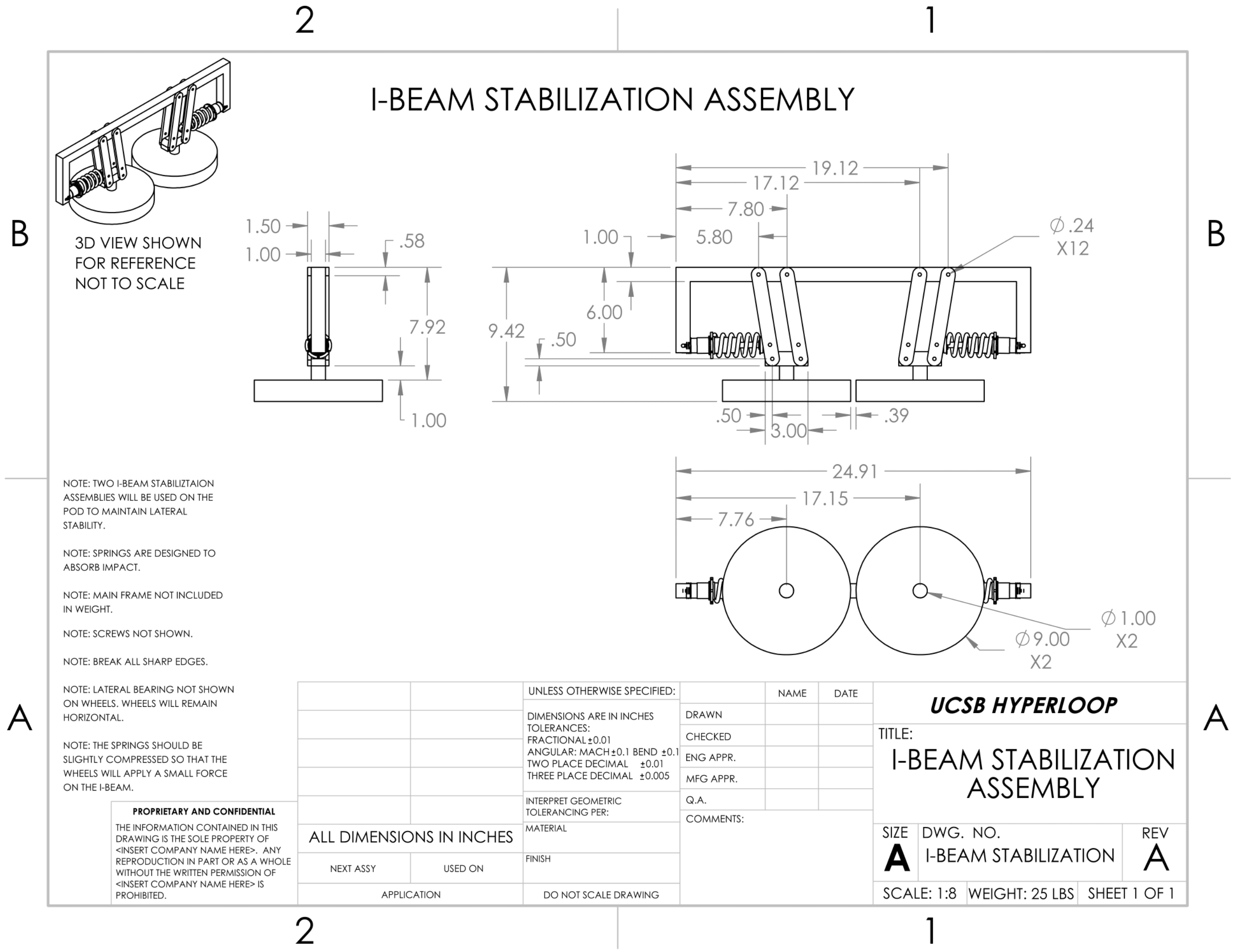
mechanical stabilization

- Inspired by roller coasters
- Uses polyurethane wheels in conjunction with spring-dampers to center along the I-beam
- **Wheels:**
  - Polyurethane with aluminum center
- **Shock absorbers:**
  - Absorb lateral movements and vibrations
  - Wheels will apply small force along I-beam
- **Links and joints**:
  - Configured to 1 degree of freedom, as verified by Gruebler's equation
- **Two assemblies:**
  - One towards the front, one towards the back
  - Each weighs 25 lbs (50 lbs total)



Road Wheel
230mm or 9.00” tread diameter

STABILITY



I-BEAM STABILIZATION ASSEMBLY
3D VIEW SHOWN FOR REFERENCE NOT TO SCALE
1.50
1.00
.58
7.92
1.00
19.12
17.12
7.80
1.00
5.80
6.00
9.42
.50
.50
3.00
.39
Ø.24 X12
24.91
17.15
7.76
Ø1.00 X2
Ø9.00 X2
NOTE: TWO I-BEAM STABILIZTAION ASSEMBLIES WILL BE USED ON THE POD TO MAINTAIN LATERAL STABILITY.
NOTE: SPRINGS ARE DESIGNED TO ABSORB IMPACT.
NOTE: MAIN FRAME NOT INCLUDED IN WEIGHT.
NOTE: SCREWS NOT SHOWN.
NOTE: BREAK ALL SHARP EDGES.
NOTE: LATERAL BEARING NOT SHOWN ON WHEELS. WHEELS WILL REMAIN HORIZONTAL.
NOTE: THE SPRINGS SHOULD BE SLIGHTLY COMPRESSED SO THAT THE WHEELS WILL APPLY A SMALL FORCE ON THE I-BEAM.
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NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±0.01
ANGULAR: MACH ±0.1 BEND ±0.1
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UCSB HYPERLOOP
TITLE:
I-BEAM STABILIZATION ASSEMBLY
SIZE
A
DWG. NO.
I-BEAM STABILIZATION
REV
A
SCALE: 1:8
WEIGHT: 25 LBS
SHEET 1 OF 1

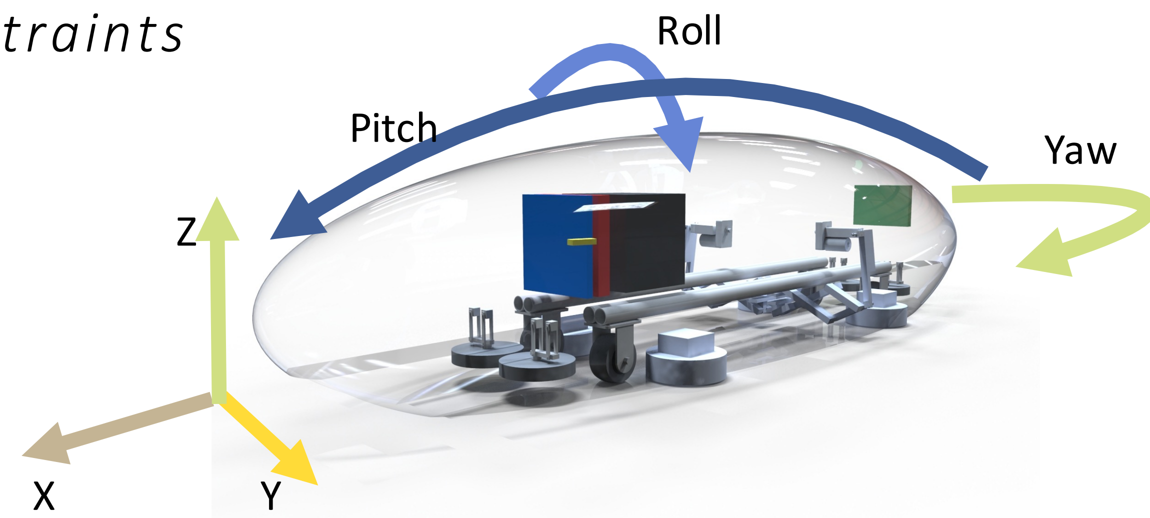
STABILITY

control system

- **Closed feedback loop:**
  - 6 inputs
    - 2 gyroscopes at front and back of pod to determine relative attitude
    - 4 ranging sensors at bottom corners of pod to determine absolute height relative to the tube
  - 4 actuators
    - Control each motor's levitation to maintain stability and correct disturbances

STABILITY

constraints

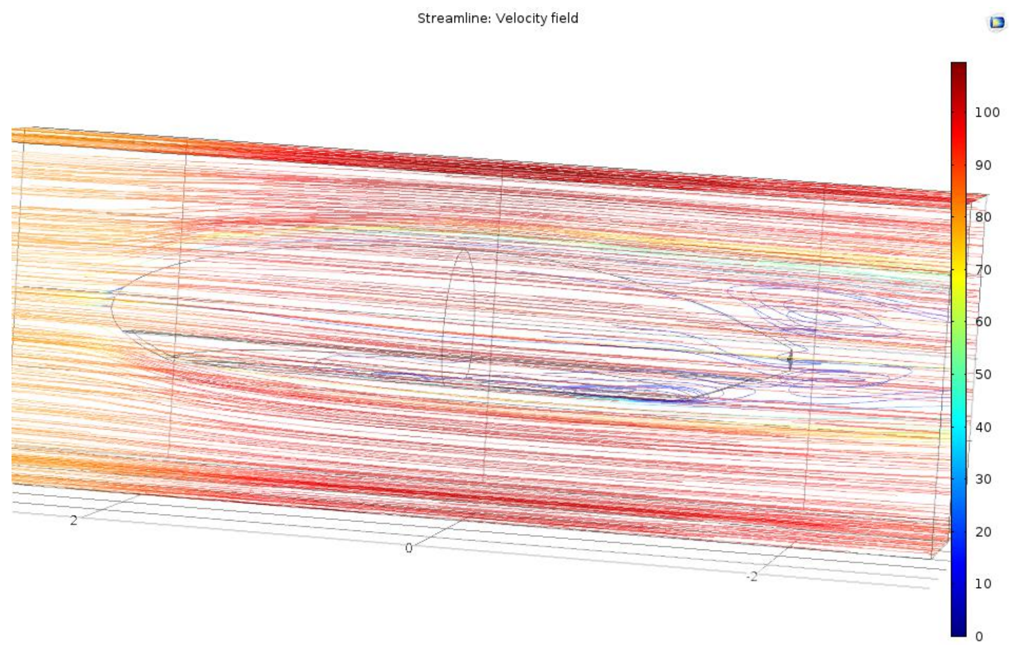


Direction	Constraint mechanism
X	Friction braking
Y	I-beam stability assembly
Z	Pod weight, maglev engines, backup wheels
Pitch	Maglev engines, geometric constraints (pod length)
Roll	Maglev engines
Yaw	I-beam stability assembly

PRESSURE

aerodynamics

- COMSOL used to find the drag coefficient of pod shell in a free-stream environment
- Decreasing pressure within the tube decreases drag
- Desired pressure for competition: 0.02 psi



$T = 27\ °C$
$v = 80\ m/s$
$\rho = 0.001686\ kg/m^3$
$P = 0.02\ psi = 137\ Pa$
$A = 0.6503\ m^2$

$F_d = 1.462\ N$
$C_d = 0.413$

NAVIGATION

position sensing

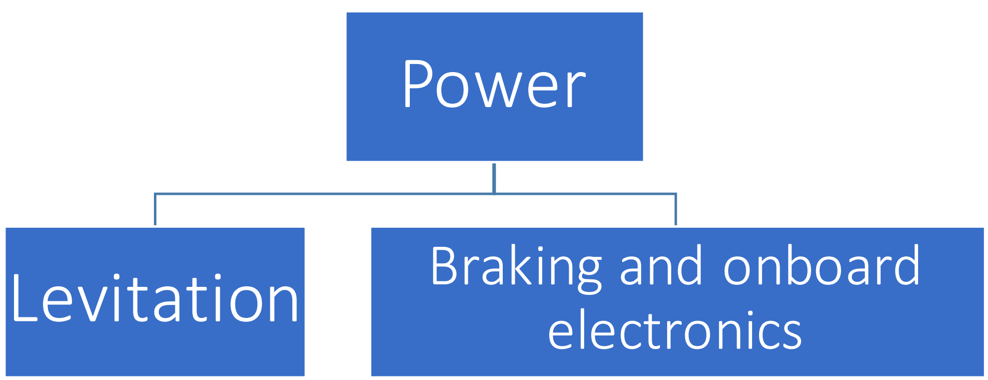
- **Dead reckoning to sense position**
  - Involves double integrating acceleration and recalibrating with an absolute value for position
- **Diffuse-reflective photoelectric sensor**
  - Recognize the reflective strips on the top of the tube
  - Absolute measure of position
  - Omron E3FB-DP13 2M
    - Analog sensor will operate reliably at all speeds
- **Accelerometer**
  - Double integrate acceleration to determine position between strips
  - Gives a reasonable prediction of position
  - STMicroelectronics LSM303DLHC
    - Must be accurate enough to avoid dramatic integral drift between strips
    - 16-bit precision = discretizations of 0.0625

POWER CONSUMPTION

subsystems

- Power consumption of entire pod system is a critical limitation of overall performance
  - Both cost and weight increase as our power specifications increase
- Will utilize the umbilical charging system during testing phases A,B, and C
- The umbilical feature is unavailable for test D (levitation at low pressure)
  - Extra battery capacity will be added to compensate (pending further time specifications)

- Two main power consuming subsystems during run time:



POWER CONSUMPTION

levitation

- Arx Pax hover engines will consume the majority of the on-board power supply during run time
  - Levitation will have its own dedicated power supply to simply power electronics

- Energy consumed during estimated run time of 35.53 s is roughly 0.12 kWh:

$P_{engine} = 3.05$ kW

P_{engine} was found using the [Arx Pax engine performance data] (page 6), based on a minimum hover height of 0.25".

$P_{tot} = (P_{engine}) \times (4 \text{ engines}) = 12.2$ kW

$t_{accel} = 3.8$ s

t_{accel} was calculated assuming 2.4g acceleration through a distance of 560ft.

$t_{brake} = 31.73$ s

t_{brake} was calculated using combined 320 lbs normal force via caliper braking on the center I-beam.

$t_{tot} = (t_{accel}) + (t_{brake}) = 35.53 \text{ s} = 0.01$ h

$E_{min} = (P_{tot}) \times (t_{tot}) = 0.12$ kWh

POWER CONSUMPTION

braking & onboard electronics

- Braking and onboard electronics systems will share a power supply, separate from the levitation system
  - Total power consumed is negligible compared to levitation system
- 12 V power supply
  - Simple to step-down to other necessary voltages of 5 V and 3.3 V

	Components	Supply Voltage
Braking (primary and fail-safe)	Linear actuators (braking) (2)	12 V
	Linear Solenoid (2)	12 V
Onboard electronics (telemetry, controls, and wireless communication)	Photoelectric sensors (2)	12 V
	Gyro/Accel/Temp/Press (2)	5 V
	Long ranging sensors (6)	5 V
	Short ranging sensors (4)	5 V
	LCD Screen (1)	5 V
	uController (2)	3.3V
	Ethernet module (1)	3.3 V

STORED ENERGY & HAZARDOUS MATERIALS

- **Stored energy**
  - Lithium Polymer (LiPO) Batteries
    - High energy density and high current draw
    - Better energy/weight ratio than Lithium Ion
    - Favorable form factor

- **Hazardous materials**
  - Pod Power Supply
    - Lithium polymer batteries contain hazardous chemicals
    - Protection circuits included to prevent excessive current draw
    - Shock-proof, puncture-proof case to surround all packs

SAFETY FEATURES

- **Emergency Braking**:
  - Predetermined maximum velocity values dictate maximum pod speeds at certain points in the tube
    - Emergency braking system activates if the actual speeds exceed values at any point
  - Linear solenoids activate emergency braking system if power loss occurs
- **Safety Wheels**:
  - Backup wheels protrude past the hover engines in case of levitation failure
  - Protects pod and track from physical damage
- **Maglev Control System**:
  - 4 ranging sensors on pod undercarriage corners give levitation height
  - High speed maglev control system regulates a stable operating height and attitude
- **WiFi Connection Loss**:
  - Enable the emergency brake if connection to the given router is lost for more than four seconds

CONCLUSION

- **Immediate focus**
  - Prototyping on-board electronics with NXP LPC4088 Developer's Kit
  - System Printed Circuit Board will begin fabrication in December
  - 3D printing models for wind tunnel testing
  - Building first iteration of pod shell

- **Next milestones**
  - Waiting for specifications on improved hover engines from Arx Pax
  - Force/strain tests on outer shell to determine actual maximum acceleration and velocity
  - Refine inner structural design
  - Make the Hyperloop a reality