BADGERLOOP

PRELIMINARY DESIGN BRIEFING

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

BADGERLOOP TEAM INFORMATION

Competition Objective
- We will design and fabricate a competition-scale pod for testing in the SpaceX Test Tube
- We plan on attending both Design Weekend and Competition Weekend

Pod Testing Category
- Levitating (non-wheeled) Pod
- Attempting to win the “Rubric” competition (for points, *not* speed)

Team Size
- 5 Executive Members
- 6 Team Leaders
- 89 General Members

www.badgerloop.com

BADGERLOOP TEAM STRUCTURE UNIVERSITY OF WISCONSIN – MADISON

Executive Team

Tieler Callazo
Team President

Brett Sjostrom
Technical Director

Sid Smith
Industry Relations

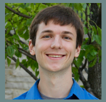
Johnnie Wagman
Team Coordinator

James Olson
Financial Director

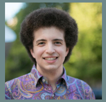
Faculty Advisers
Dr. Michael Cheadle
Dr. Christropher Rutland

Team Leaders

Austin Jeffries
Mechanical



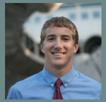
Duncan Adams
Braking



Eric Amikam
Electrical

Chase Roossin
Software

Alex Balister
Safety



Michael Knippen
Operations

General Members

Kevin Bannerman
Jonathan Barker
Matthew Benbenek
William Black
Jesse Bonney
Derek Burling
Andrew Bugliosi
Bill Carpenter
Ryan Castle
Brandon Cole
Patrick Cummings
Kyle Curry
David Doellstedt
Andrew Duplissis
Aaron Faubel
Clayton Fellman
Garrett Frankson
Maxwell Goldberg
Gabe Gottlieb
Kyle Grieger
Maximillian Henry
Kevin Herro
Peter Hornung
Kunal Jadhav
Nicholas Jaunich
Zachary Kant
Mackenzie Kilness
Katherine Konsor
Bryce Kramer
Marguerite Loose
Zhengyang Lou
Jack McGinty
Ryan McMurty
John McShane
Benjamin Moldenhauer
Kellen Moore
Jonathan Murray
Austin Nellis
Jacob Nesbit
Nathan Orf
Lexi Oxborough
Brett Paris
Christopher Park
Jonah Pefrey
Thomas Petrovic
Carlos Pimentel
Samuel Pochyly
Guru Prasad
Noah Pulvermacher
Daniel Quigley
Kyle Raddatz
Daniel Radtke
Noah Rhodes
Jackson Roach
Elijah Ruder
Seth Reuter
Christopher Rupel
Brandon Schadrie
Samuel Scheffler
Eric Schirtzinger
Jayce Schmidtknecht
Justin Shrimmer
Alec Schultz
Jacob Seibert
Amarah Sharif
Connor Sheedy
Jacob Sibert
Ritvik Sinha
Stephen Slattery
Ryan Sreenivasam
Tristan Steiner
Eric Sutton
Colin Swee
Saman Tabatabai
Luke Tilkens
Selix Tsao
Abhay Venkatesh
Park Walter
Ben Webster
Tucker White
Justin Williams
Andrew Winans
Evan Wolfenden
Johnny Yan
Rachel Yehle
Jameson Zaballos
Troy Zeuske
Jia Zhuang
Elizabeth Zunker

SUMMARY OF KEY DESIGN OBJECTIVES

Pod Dimensions and CFD Analyses

Mass and Power Consumption of Subsystems

Braking and Service Propulsion Mechanism

Stability Mechanism

Levitation Mechanism

- **Recommend laminate aluminum track opposed to solid aluminum**

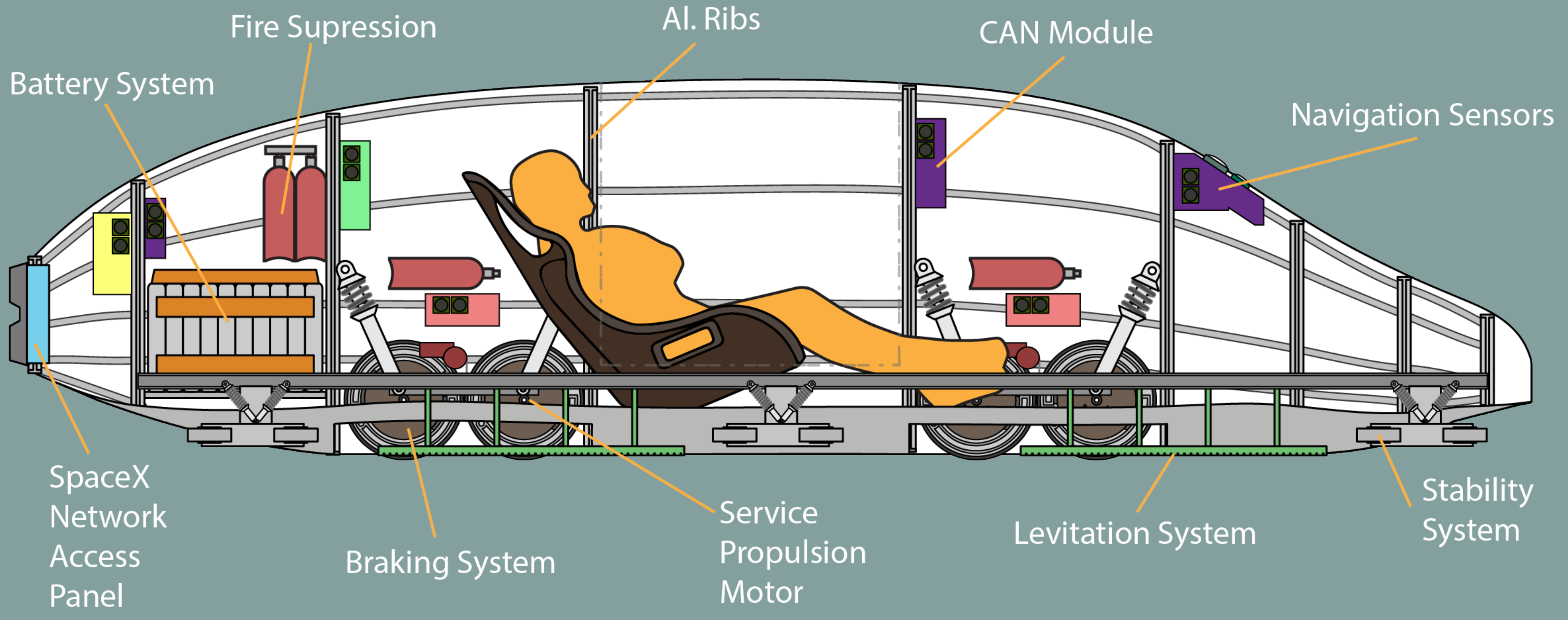
Navigation Mechanism

Mechanical and Electrical Systems Overview

Stored Energy and Hazardous Materials

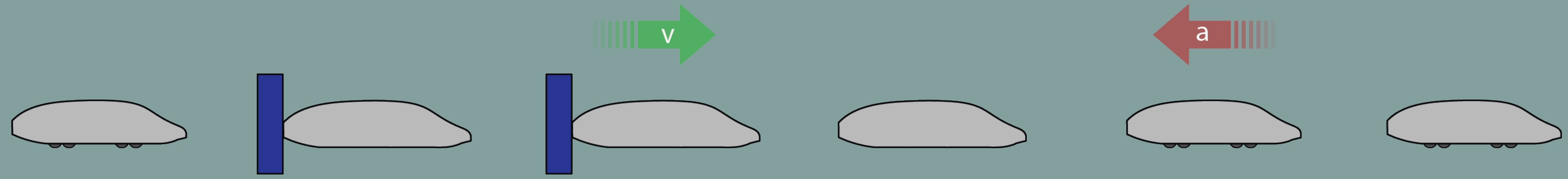
Safety Features Included For Each Mechanism

SYSTEM OVERVIEW



COMPETITION LOGISTICS

Tube Operating Pressure: 100 [Pa]



1) Load pod

Wheels down

2) Pod interfaces with pusher

Wheels up
Rolls on Bearings

3) Pusher accelerates pod

Wheels up
Levitation begins

4) Pod separates from pusher

Wheels up
In Flight

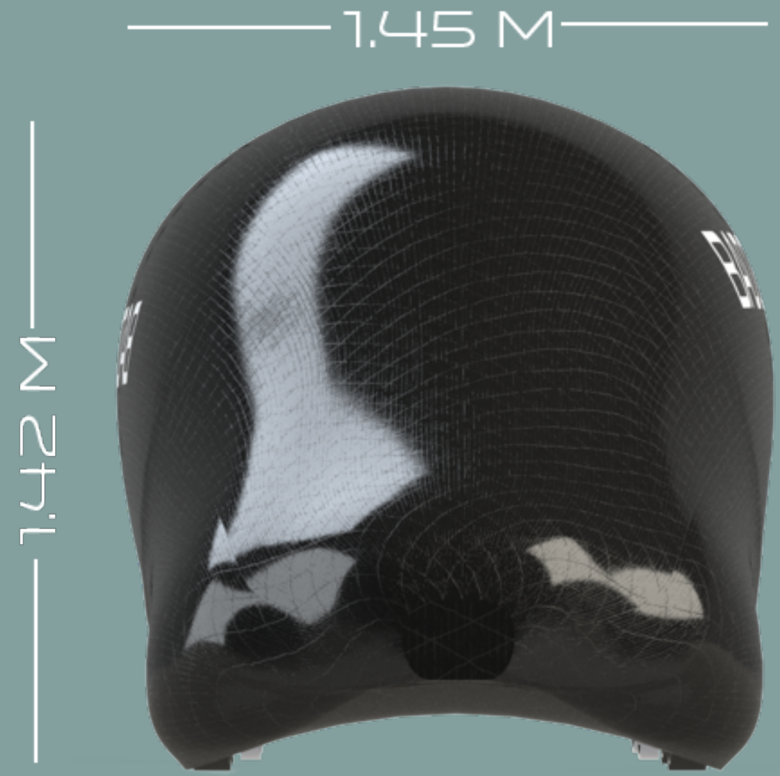
5) Wheels deploy and braking is engaged

Wheels down
Braking begins

6) Pod comes to stop and exits

Wheels down

POD DIMENSIONS



MASS AND POWER CONSUMPTION

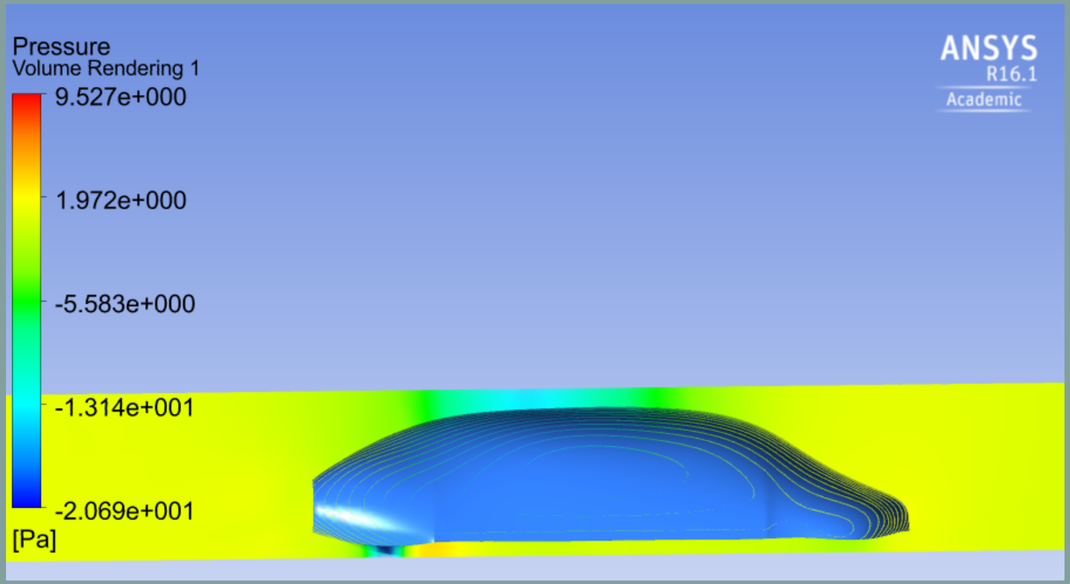
Subsystem	Mass [kg]	Power [Wh]
Aluminum Frame	300	-
Carbon Fiber Shell	209	-
Braking and Suspension System	251.5	6.5
Levitation System	60	-
Service Propulsion System	20	140
Batteries	21	-
CAN System	20.5	0.2
Stability System	12	-
Sensors (All)	0.5	0.1
TOTAL:	**894.5**	**146.8**
EXCESS CAPABILITY:	**605.5**	**83.2**
TOTAL WITH PAYLOAD:	**1500**	**230**

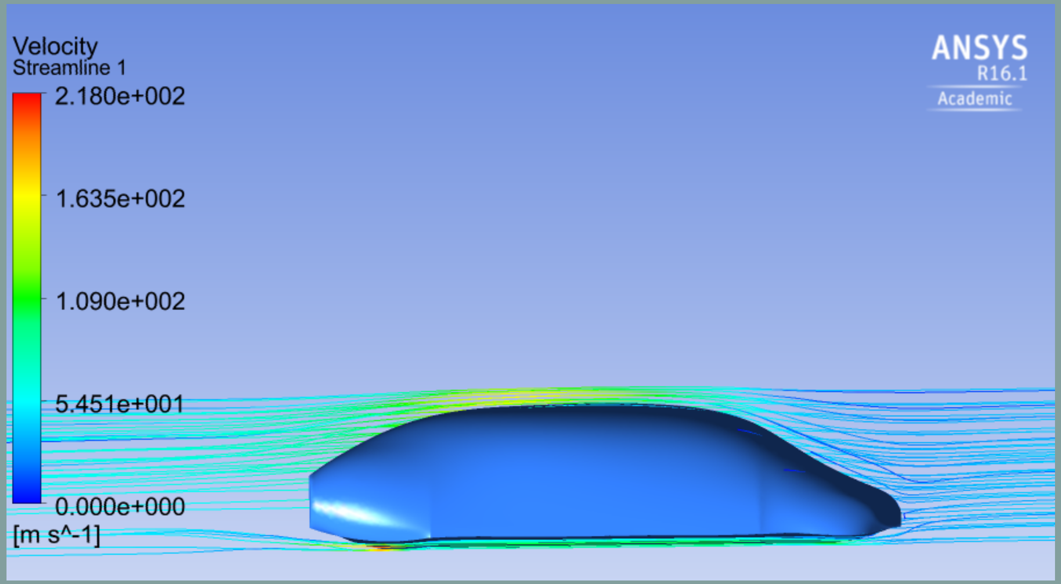
OUTER SHAPE

Maximum aerodynamic drag force

9.52 [N]

Outer shape optimized to reduce drag and minimize high pressure regions





STRUCTURE

Outer Shell Material

- Shell: Carbon Fiber
- Frame: 7075-T6 Aluminum

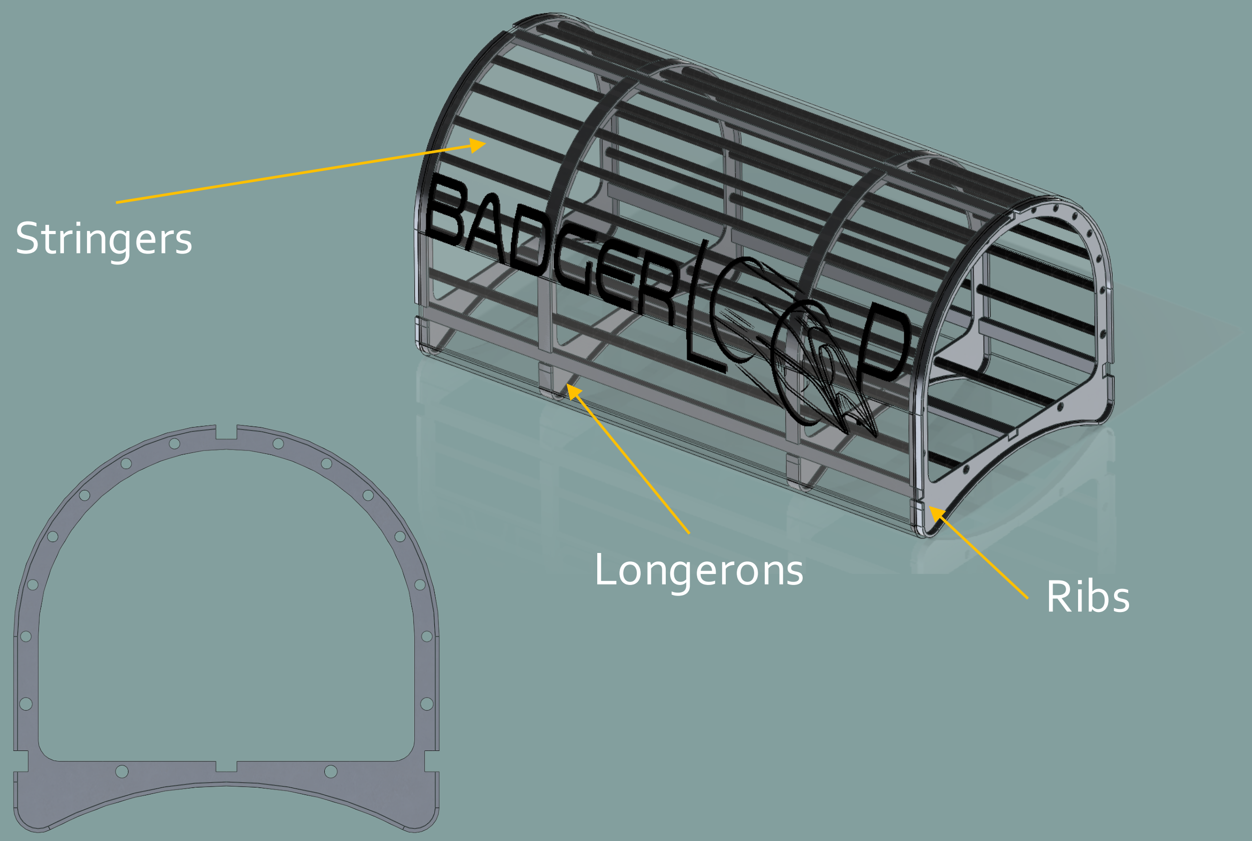
Structure Mass

- From current model: 509 [kg]

Structure Build Materials

- Ribs: CNC machined aluminum
- Longerons: Aluminum Stock
- Inner-frame Stringers: Aluminum Tube Stock

STRUCTURE



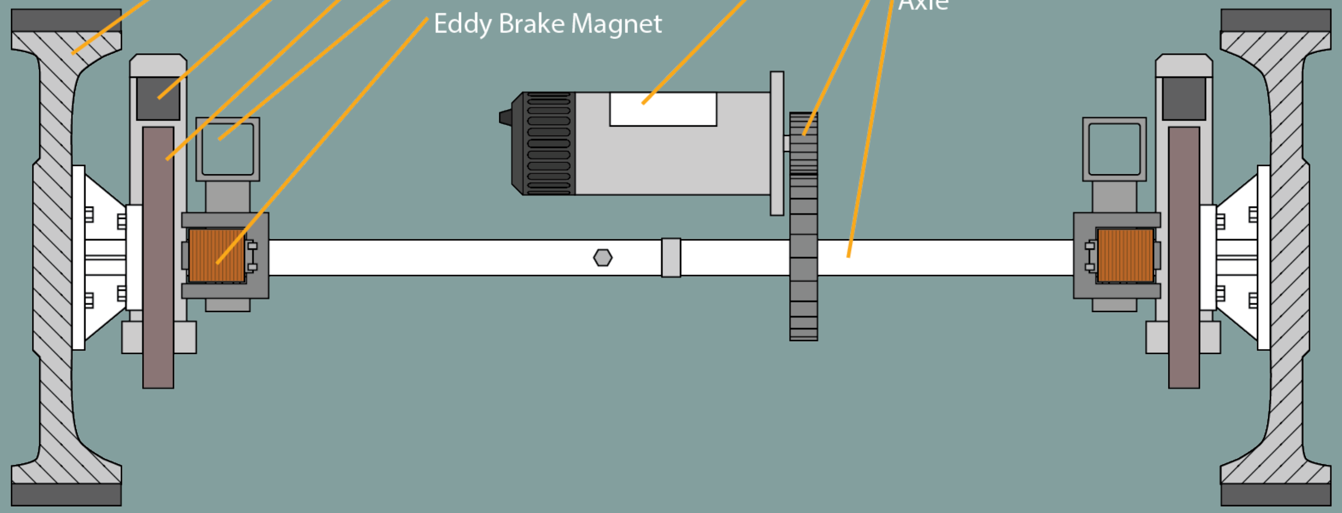
Semi-monocoque design

- Based on design of experimental aircraft

Ribs, stringers, and longerons take majority of load

Crumple zone designed in front of pod to improve passenger safety in the event of collision

BRAKING AND SERVICE PROPULSION SYSTEM



Specifications:

- Wheel Diameter: 42 [cm]
- Axle Length: 107 [cm]
- Total Rotating Mass: 157 [kg]
- Total System Mass: 260 [kg]

Four axles, eight wheels total

Eddy Current Braking System

- Two rotors and two electromagnets per axle provide non-contact braking

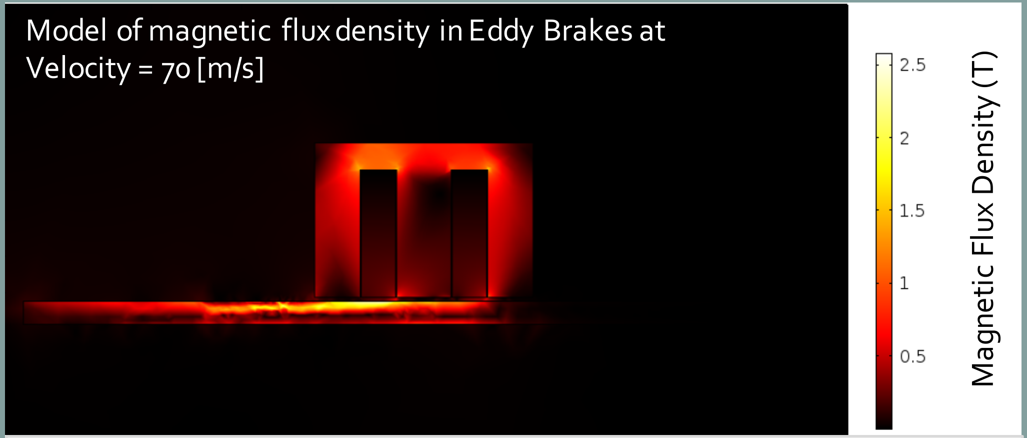
Self-Energizing Drum Braking System (2LS)

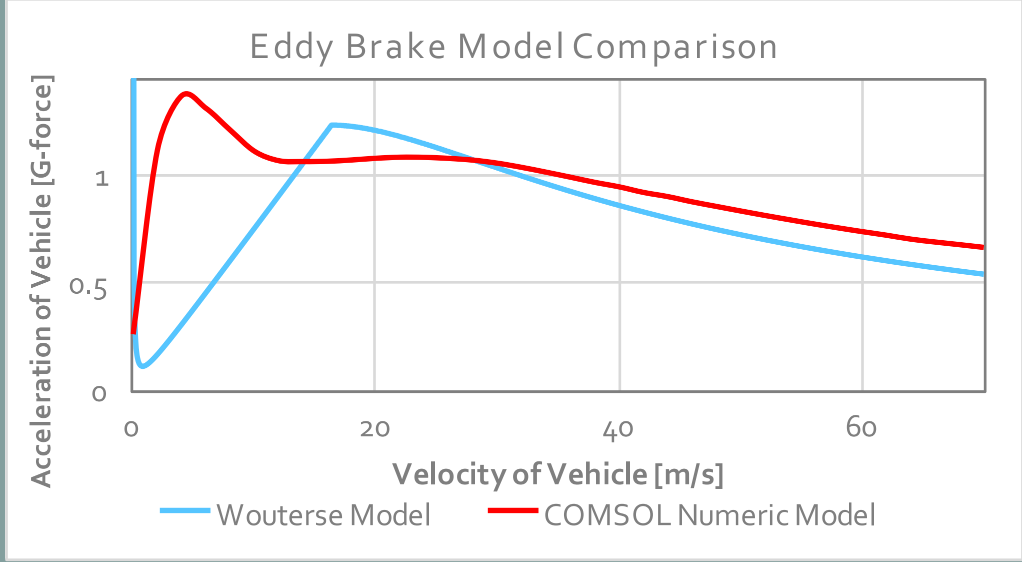
- Short-shoe external drum brakes do not require external power to stop

Service Propulsion System

- Can drive pod to end of tube in emergency
- DC brushless motor

EDDY CURRENT BRAKING SYSTEM





Consists of one DC electromagnet paired with an Iron rotor per wheel

Powered from regenerative brake motor

- Motor only draws enough power to supply eddy brake electromagnets
- Draws approximately 300 [W] at peak current
- Regenerative Brake motor provides additional small amounts of stopping torque due to power draw

Generated current in disc is dissipated as heat

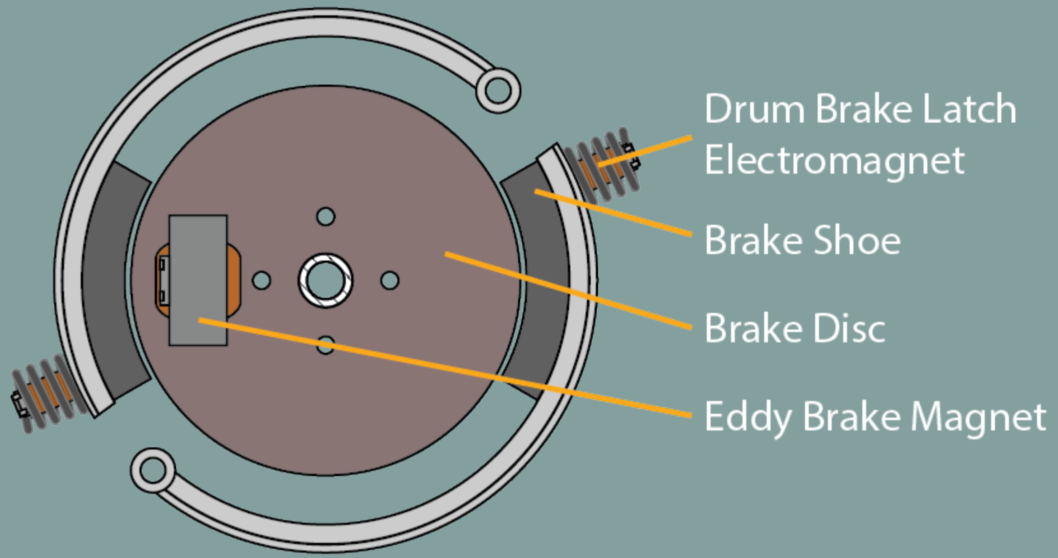
- ~100 [C] temperature rise per rotor assuming minimal convection

Braking torque modeled with Wouterse[1] model as well as COMSOL numeric model for comparison

- Similar acceleration profiles in the high speed region
- Braking acceleration for both models shown at left
- Will be constructing prototype of eddy current brake system before Final Design to verify low-speed region

1. Wouterse Model: Critical Torque and Speed of Eddy Current Brake with Widely Separated Soft Iron Poles by J.H. Wouterse

EMERGENCY BRAKING SYSTEM (DRUM BRAKE)



Twin-Leading (2LS) External Short-Shoe Brake

- Self-energizing- geometry chosen so that friction force pulls brake shoe into drum
- Not designed for repeated operation, brake shoes will need to be replaced after emergency braking

Fail-safe

- Electromagnet holds brake shoe off of brake disc when not in use
- Spring pushes brake shoe into rotor if pod loses power

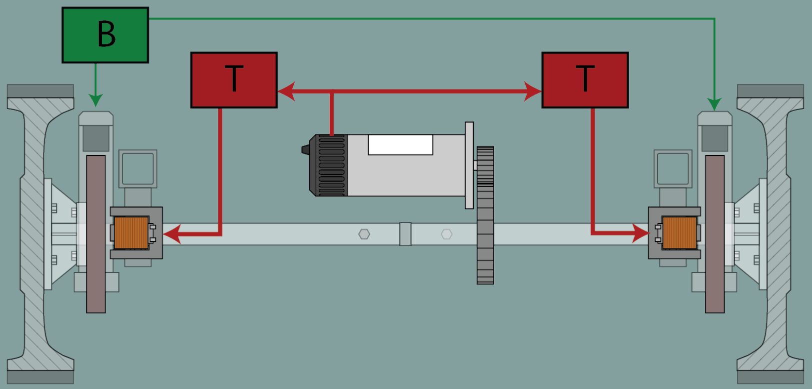
Relies on friction to stop

- Sintered metal or carbon brake shoe on machined 1020 steel rotor

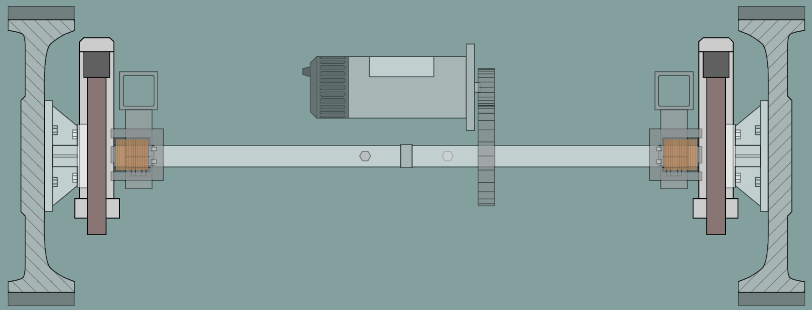
Antilock Braking

- Force balance chosen to result in net force near zero at Latch Electromagnet, allowing braking force to be modulated for ABS

BRAKING SAFETY FEATURES AND FAULT TOLERANCE



Normal Braking: Regenerative motor powers eddy brakes and battery prevents drum brakes from engaging



Emergency Braking: Requires no power supplied anywhere

Loss of Axle

- Can sustain loss of any two wheels without reduced braking capacity
- Can lose one rotor per axle without asymmetric braking
- Loss of any two axles reduces braking capacity to half

Loss of Power

- Emergency drum brakes automatically engage with loss of power
- Eddy current brakes draw power from regenerative motor on each axle, not central battery
- Deployment system will engage if pod system loses power

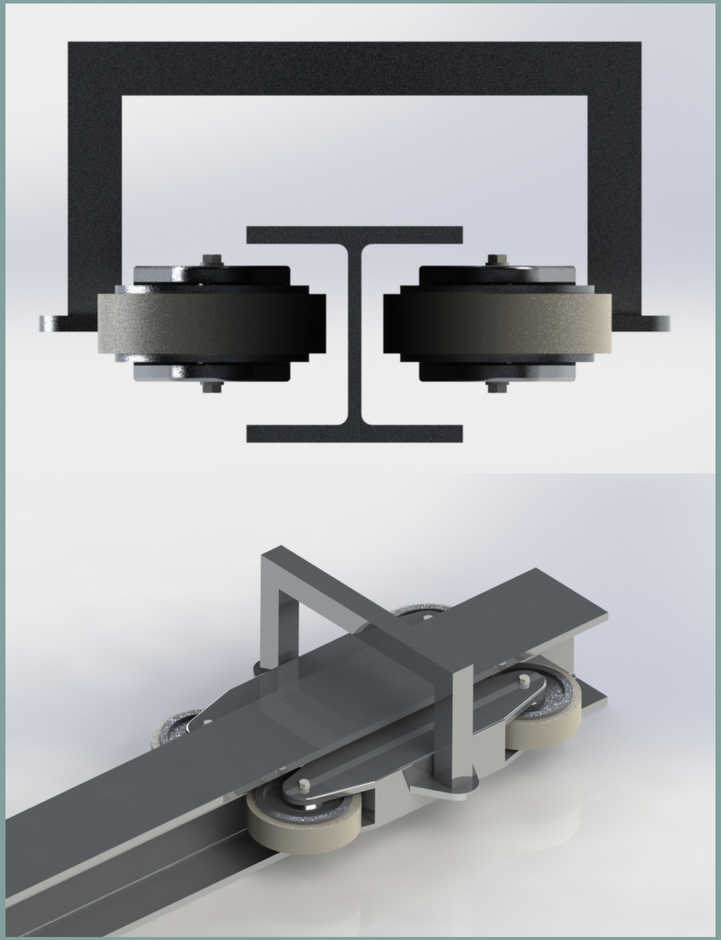
Skid condition (track surface contamination)

- Eddy current brakes will be Pulse-Width Modulated (PWM) to provide antilock braking
- Drum brakes are designed to be toggled on and off to allow for antilock braking while battery power is supplied

Loss of levitation

- Wheels designed to deploy within one second of loss of power, passive Halbach Arrays will sustain lift due to pod velocity
- Wheels will deploy if pod loses lift and contacts ground
- Axle suspension system will still provide shock absorbing for impacts when stowed

POD STABILITY MECHANISM



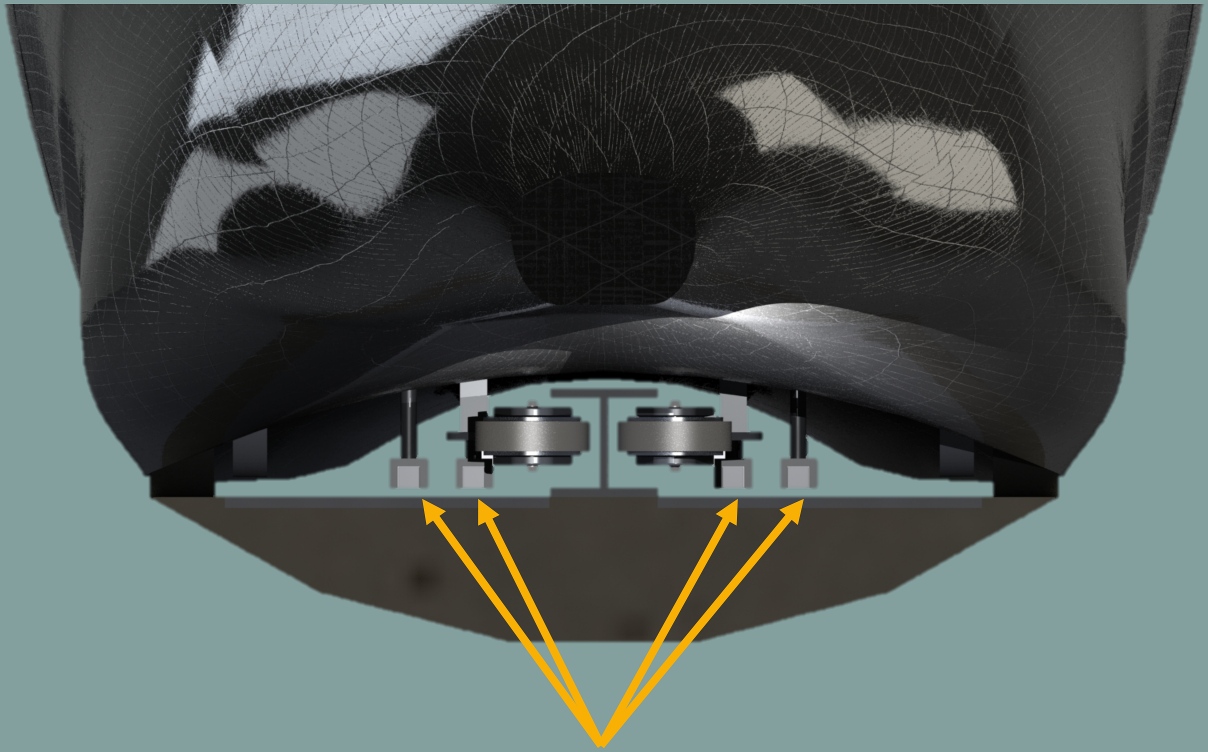
High performance roller bearings on center rail provide lateral stability

- Passive system
- Dynamic Load Capacity: 6005 [N]
- Max Rated Rotational Speed: 25,000 [RPM]

Pod Stability Safety Features

- 3 sets of bearings to ensure rail alignment
- Self-centering and can accommodate slight fluctuations in pod trajectory

POD LEVITATION MECHANISM



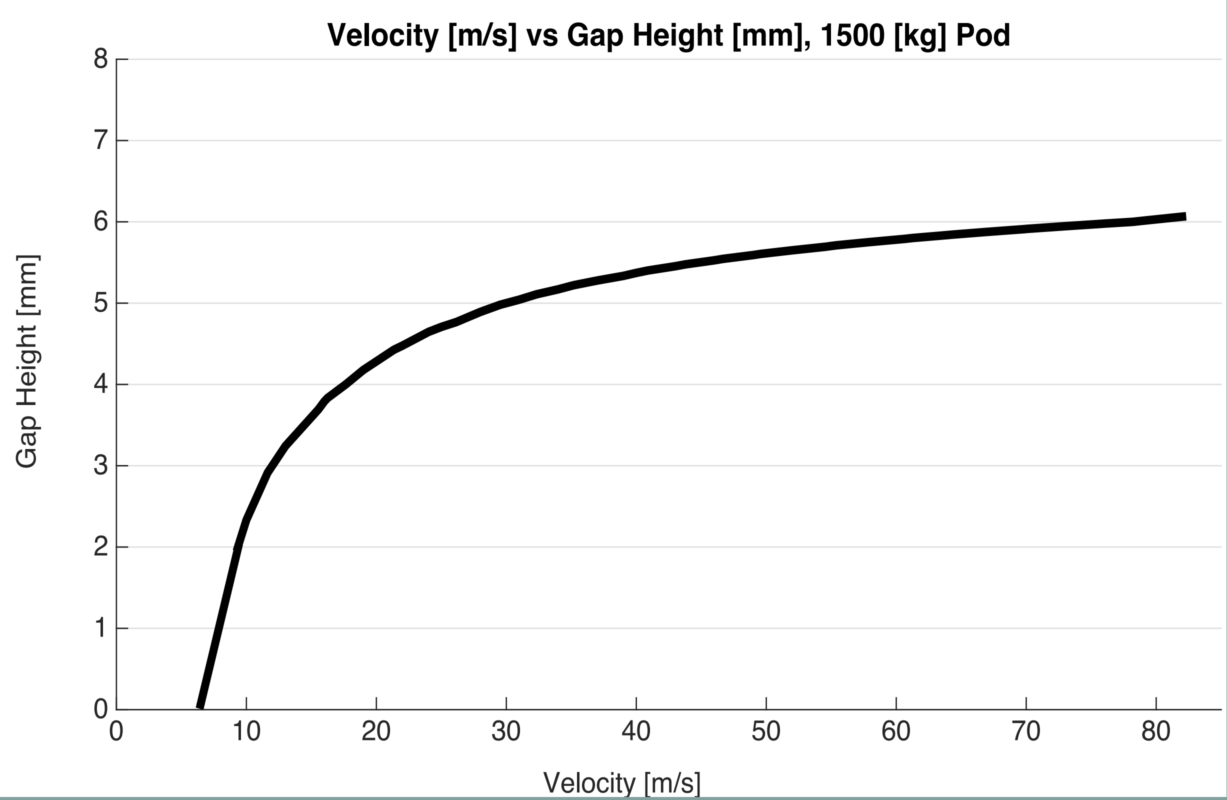
Passive Halbach Arrays

Passive Halbach Arrays

- 370 25 [mm] Neodymium Iron Boron Grade N52 Permanent Magnets
- Can support total mass of 1500 [kg]
  - Pod design weighs 894.5 [kg]
- Levitates at 2 [mm] above aluminum sub track when traveling over 10 [m/s]

While engaged with SpaceX Pusher, pod will roll on high performance bearings until levitation is achieved

POD LEVITATION MECHANISM



Passive Halbach Arrays designed for 2 [mm] of lift at 10 [m/s]

Electromagnetic Drag is induced on pod from eddy currents in aluminum track

- Initial Electromagnetic Drag Force: 2940 [N]
  - Aerodynamic drag is negligible compared to electromagnetic drag
- Maximum Lift to Drag ratio: 4.7

Would like to see Laminated Aluminum Track for decreased electromagnetic drag[2]

- Maximum Lift to Drag Ratio: 100-150
- At least 20x better performance than current proposed aluminum track

2. The Inductrack Approach to Magnetic Levitation. Richard Post and Dmitri Ryutov.

POD LEVITATION SAFETY FEATURES

Halbach Arrays provide passive fail-safe levitation

- Upon loss of power the pod will continue to levitate with a gradual decrease in height and speed
- Emergency wheels will deploy before pod would contact ground

High performance bearings will contact ground instead of magnets if wheels fail to deploy

POD NAVIGATION MECHANISM

Pod Coordinate Determination

- Multiple proximity sensors mounted on the exterior of pod monitor pod-tube and pod-rail distances.
- Optical sensors monitor colored strips on top of the tube to determine pod velocity and location
- 6 accelerometers – 2 in the front, 2 in the middle, and 2 in the back
  - Kinematic calculations from accelerometers will be error-checked and reset every time the pod detects a new colored strip

Control system will have built-in trigger values to activate emergency brakes to ensure the pod brakes before egress area

Pod Navigation Safety Features:

- Redundant sensors for navigation control and coordinate location
- Loss of pod location in tube will result in emergency brake deployment
- Negligible added mass/power consumption

ELECTRICAL SYSTEM OVERVIEW

System based on CAN (Controller Area Network) with 5 total module nodes

- Modules are grouped by functionalities
- Utilize constant communication to disperse data acquisition, controls, and processing across 5 different microcontrollers

12 [V] Battery Pack powers control systems and fail-safe braking electromagnets

Includes a control panel for easy monitoring, debugging, reprogramming, and fuse/relay swapping

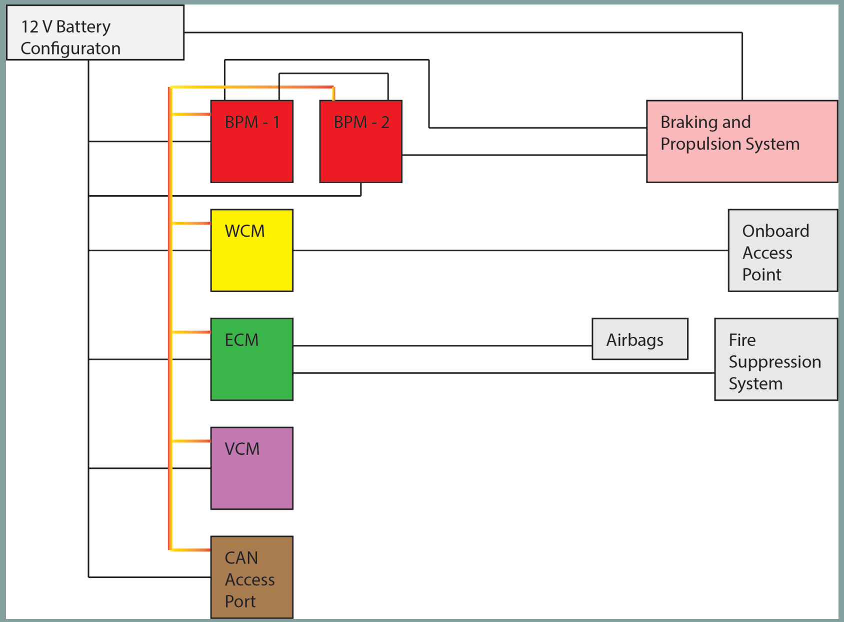
CONTROLLER AREA NETWORK (CAN)

BPM (Braking and Propulsion Module) – is responsible for moving the vehicle at low speeds (<5 mph), and for deploying/controlling/retracting the Axle Units. There will be 2 identical versions of this module, one for each pair of Axle Units.

WCM (Wireless Connectivity Module) – is responsible for taking in CAN data from other modules and relaying it to the server. It is also responsible for receiving commands from the server (Emergency Brake, Start Levitation, etc.) and properly alerting the necessary modules.

ECM (Environmental Control Module) – is responsible for monitoring various hazardous vehicle environment conditions, and appropriately alerting the rest of the system or neutralizing the hazard independently.

VCM (Vehicle Control Module) – is responsible for general data acquisition and basic vehicle controls. It is also responsible for reporting all dangerous vehicle conditions (high temperatures, incoming object, unresponsive subsystems, etc.).



BATTERIES

Possible Chemistries – ***Lithium Iron Phosphate*** is likely candidate

- NMC (Nickel Manganese Cobalt) – high energy density, low cost, low heat rise
- ***LFP (Lithium Iron Phosphate) – high discharge rate, relatively more safe***
- NCA (Nickel Cobalt Aluminum) – high energy & power densities, high cost, relatively less safe

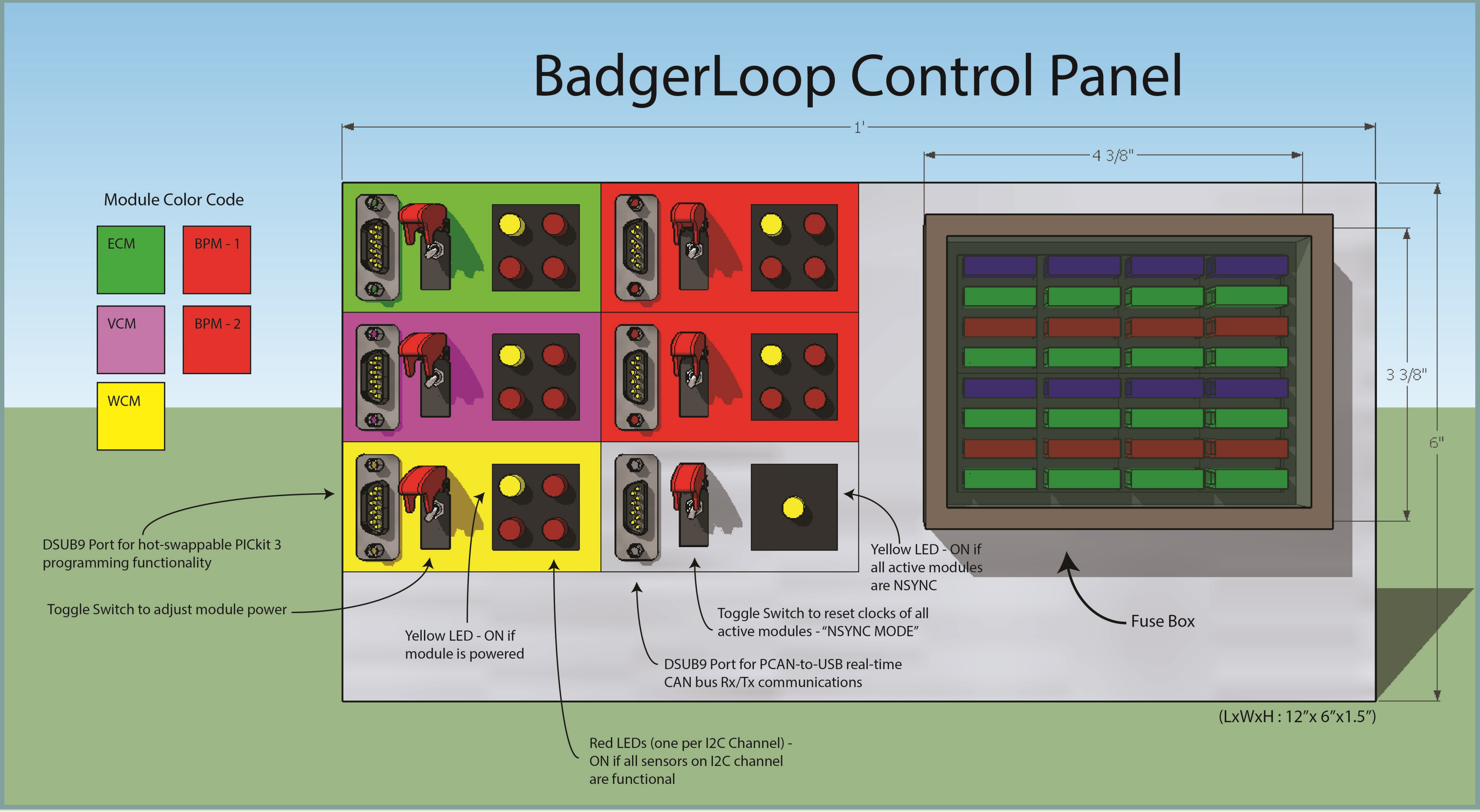
Management

- Battery management factors such as State of Charge, charge/discharge limiting, and thermal triggering will be handled by a CAN-enabled controller compatible with the pack configuration
  - Battery Control Module may be designed and programmed to handle these factors using current shunts and amp-hour integration

Cooling

- Unless more detailed calculations show a dangerous heat rise during charge or discharge, the internal cooling provided with the pack configuration will suffice as the only battery cooling method

EXTERIOR ELECTRICAL/SOFTWARE CONTROL PANEL



ELECTRICAL SAFETY FEATURES

Sensor redundancy reduces chances of single-point failures

On-board computer system will control majority of failure mode responses including mechanical actuation

Securing electrical connections reduces chances of erroneous signals/power losses

High quality sensors allow for more accurate and reliable data

- Ensures that other control modules can utilize these measurements with no inherited risk

Numerous tests prior to competition run will ensure pod software handles each failure mode appropriately

SOFTWARE SYSTEMS

CAN modules communicate using the CANopen protocol

- Each module will have a set of unique CAN identifiers that dictate content and priority of each CAN message
- Modules will have CAN identifier-based filters, making it easier for each module to parse only the CAN messages relevant to its operation

The modules will have various sensors that will be communicating over I2C, SPI, or analog

A centralized dashboard and control panel will be used to monitor and control pod operations

- This will be available on mobile and web platforms

STORED ENERGY & HAZARDOUS MATERIALS

Stored Energy Systems			Hazardous Materials	
Description	**Amount**	**Energy Amount/ Type**	**Description**	**Amount**
Lithium Iron Phosphate Battery	2.3 [kg]	230 [Wh]	Lithium Iron Phosphate Battery	2.3 [kg]
Halon Fire Suppression System	5 [kg]	17.23 [MPa] Compressed Gas	Halon Fire Suppression System	5 [kg]
Suspension Leaf Springs	8	747 [J]	Neodymium Iron Boron (NdFeB) Permanent Magnets	50 [kg]

SAFETY FAILURE MODES & EFFECTS

Two separate failure mode documents will be complied for the final design package:

- Failure Mode List #1: Competition related failures
- Failure Mode List #2: Future scalability concerns

Color coded system:

- Red - Critical Failure (life safety is at risk)
- Yellow - Moderate Failure (working through fault tolerance)
- Green - Small Failure (normal functionality)

Failure ID#		Emergency Event	Outcome w/ no Mitigation
OP001	Red	Over Speed in Tube	High G loading on pod
OP002a	Yellow	Under Speed in Tube < 100 mph	Obstruction hazard to next pod
OP002b	Green	Under Speed in Tube > 100 mph	Obstruction hazard to next pod
OP003a	Yellow	Pod Stuck in Tube with Low Speed Propulsion Loss	Obstruction hazard to next pod
OP003b	Red	Pod Stuck in Tube due to Collision	Obstruction hazard to next pod

BADGERLOOP VIRTUAL REALITY SIMULATION

Virtual Reality (VR) system enables bystanders to experience front view of pod

VR Headset will simulate the surrounding landscape of the pod as if the tube were transparent

- Drone to be flown over path of track to capture surrounding imagery

Dynamic Chair will be built to simulate physical response of pod

- Dynamic Chair outside the pod will allow virtual passenger to feel the vibration and acceleration of the chair within the pod