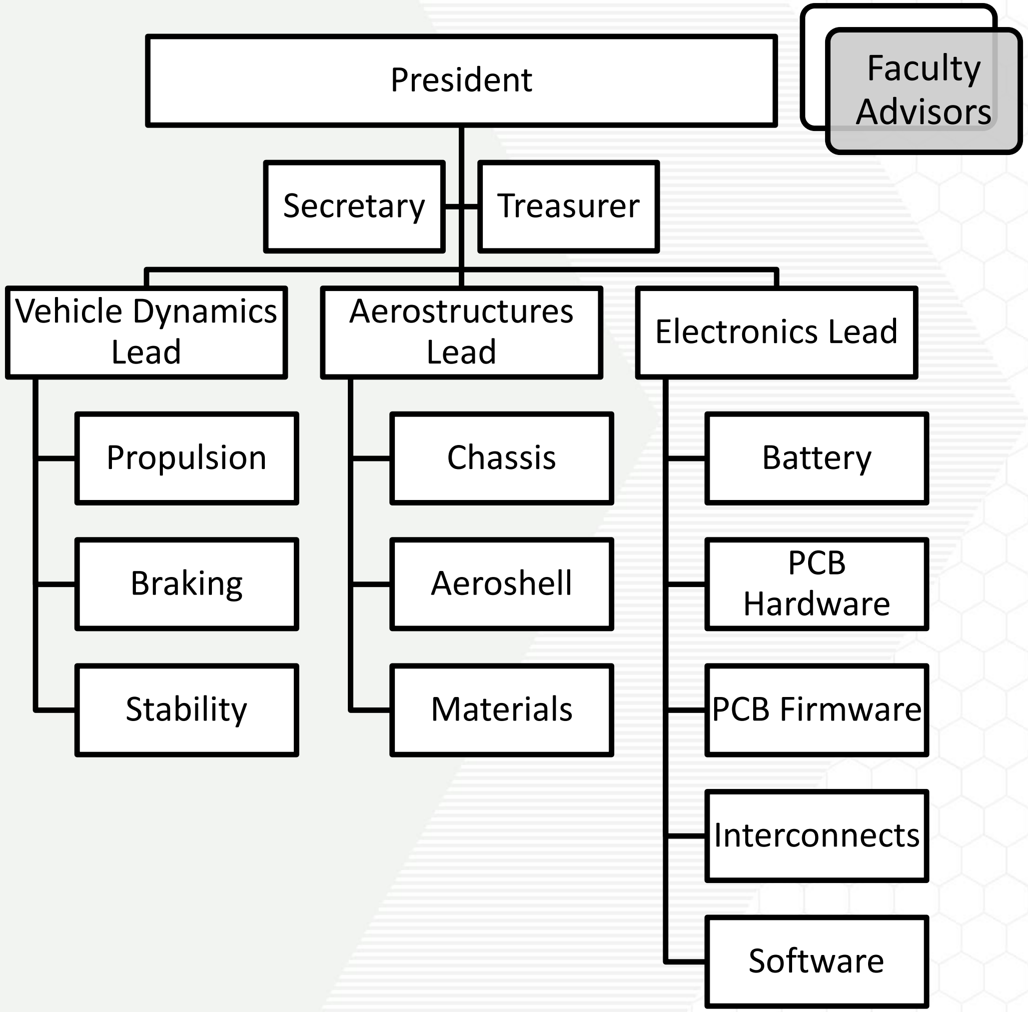
GT HYPERJACKETS PRELIMINARY DESIGN BRIEF

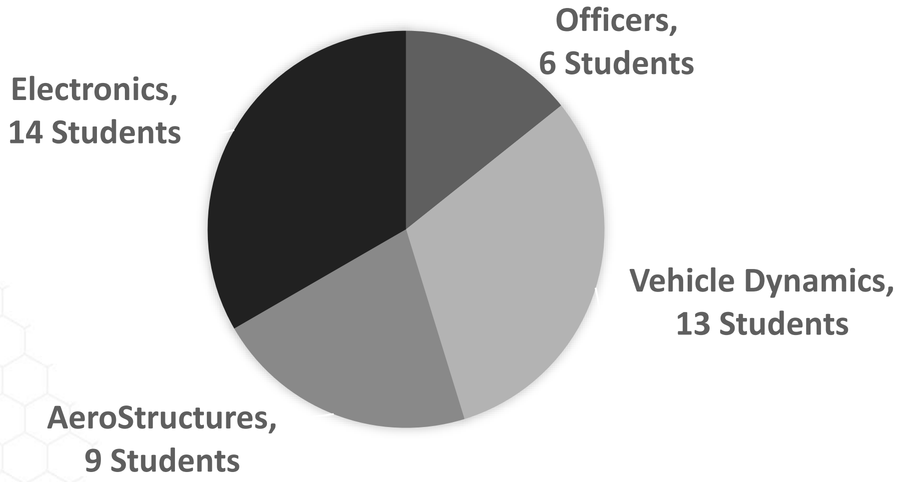
2019 SPACEX POD COMPETITION

CREATING THE NEXT®

TEAM STRUCTURE AND ORGANIZATION



- President
  - Faculty Advisors
  - Secretary
  - Treasurer
  - Vehicle Dynamics Lead
    - Propulsion
    - Braking
    - Stability
  - Aerostructures Lead
    - Chassis
    - Aeroshell
    - Materials
  - Electronics Lead
    - Battery
    - PCB Hardware
    - PCB Firmware
    - Interconnects
    - Software

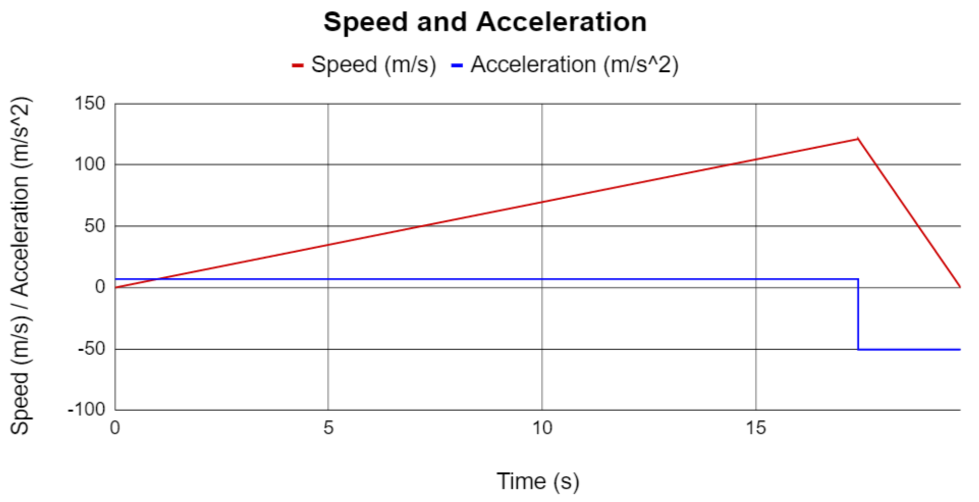


- 40+ Undergraduate and Graduate Students
- Students from Mechanical Engineering, Aerospace Engineering, Computer Science, Computer Engineering, and Electrical Engineering Majors

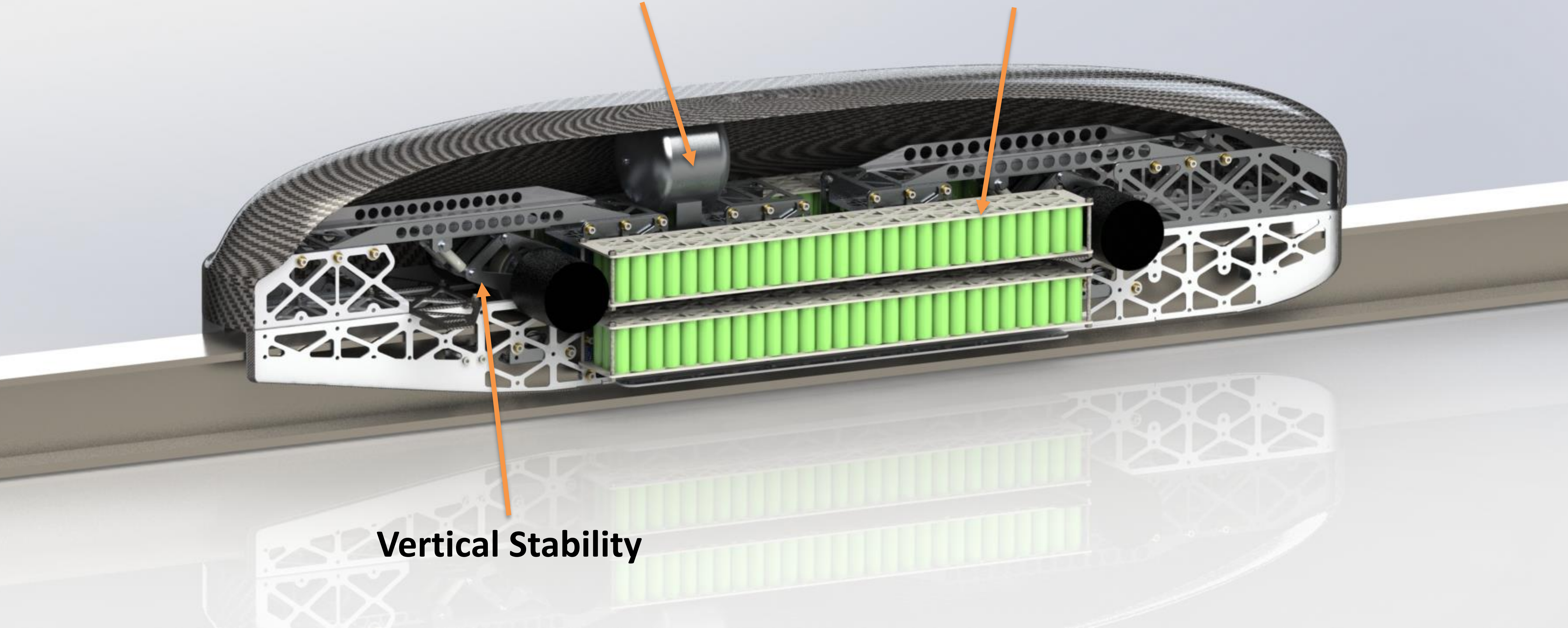
POD OVERVIEW

- **Max Velocity:** 121 m/s
- **Max Acceleration:** 0.71 g
- **Max Deceleration:** 5 g
- **Total Power Consumption (Peak):** 92 kW
- **Pod Position at End of Run:** 1180 m
- **Pod Dimensions:** 1.7m x 0.38m x 0.38m
- **Pod Mass:** 100.2 kg

System	Mass (kg)
Aerostructures	10.3
Stability	2.5
Braking/Pneumatics	7.9
Propulsion	26.7
Electronics	10.8
Power	42
Total Mass	**100.2 kg**



POD OVERVIEW

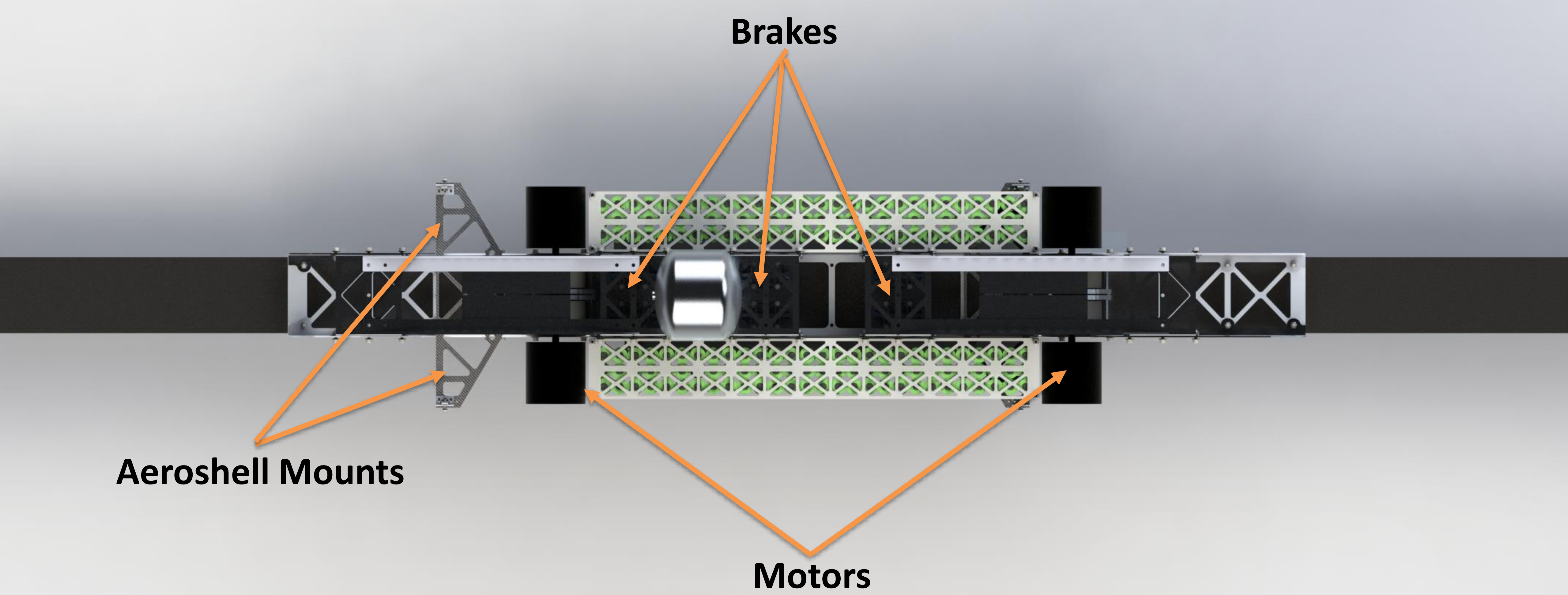


Air Tank

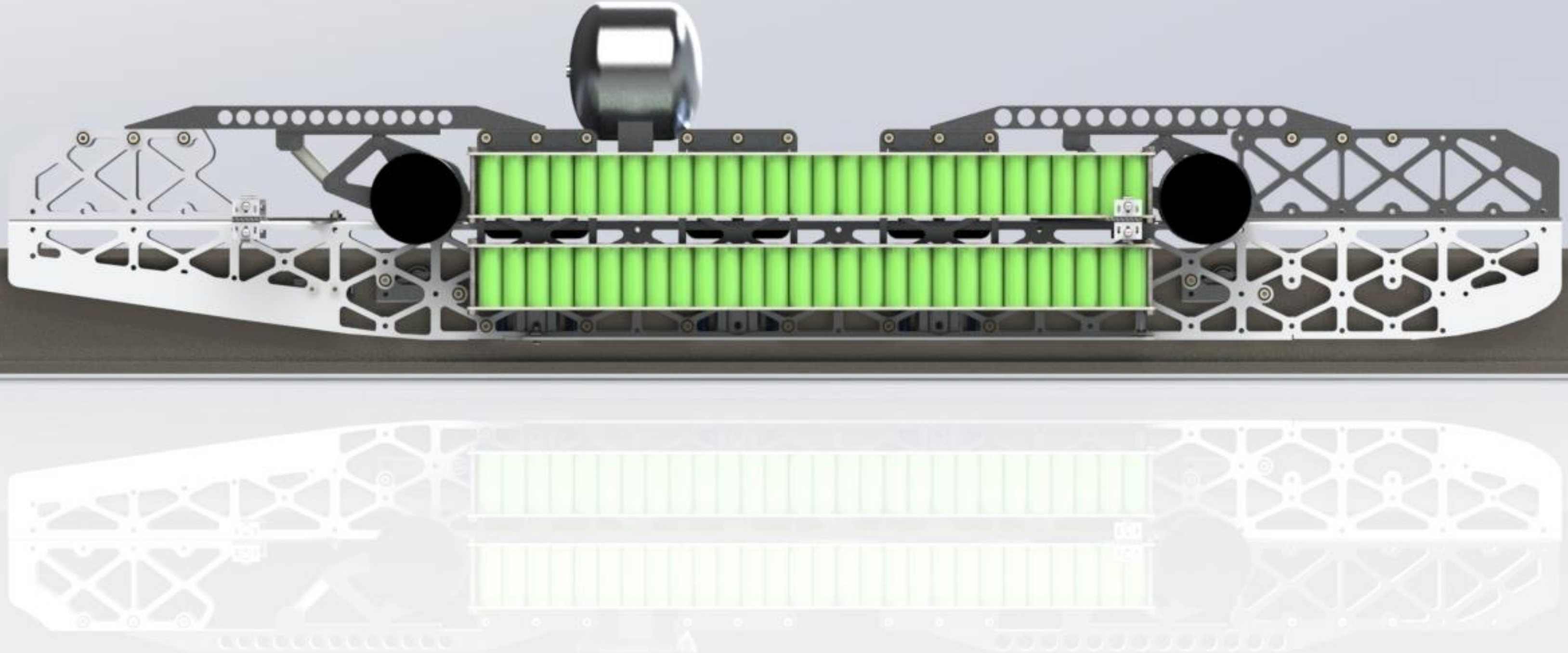
Battery Module

Vertical Stability

POD OVERVIEW



POD OVERVIEW



POWER SYSTEMS: OVERVIEW

High Power Battery

540 A123 26650 Lithium Ion Cylindrical Cells (27S5P)

- Number of Battery Cells Per Module: 135
- Number of Battery Modules: 4 (one per motor)
- Max Burst Power Capacity Per Module: 53.5 kW
- Continuous Power Per Module: 31.2 kW
- Total voltage Per Module: 89.1 V
- Total capacity Per Module: 12.5 Ah
- Total stored energy Per Module: 4.01 MJ (1.11 kWh)
- Single Module Configuration: 27 packs in series. Packs interlaced in 'L-shaped" configuration, as shown in Figure.
- Single battery module dimensions: .73 m x .0650 m x .078 m

Low Power Battery

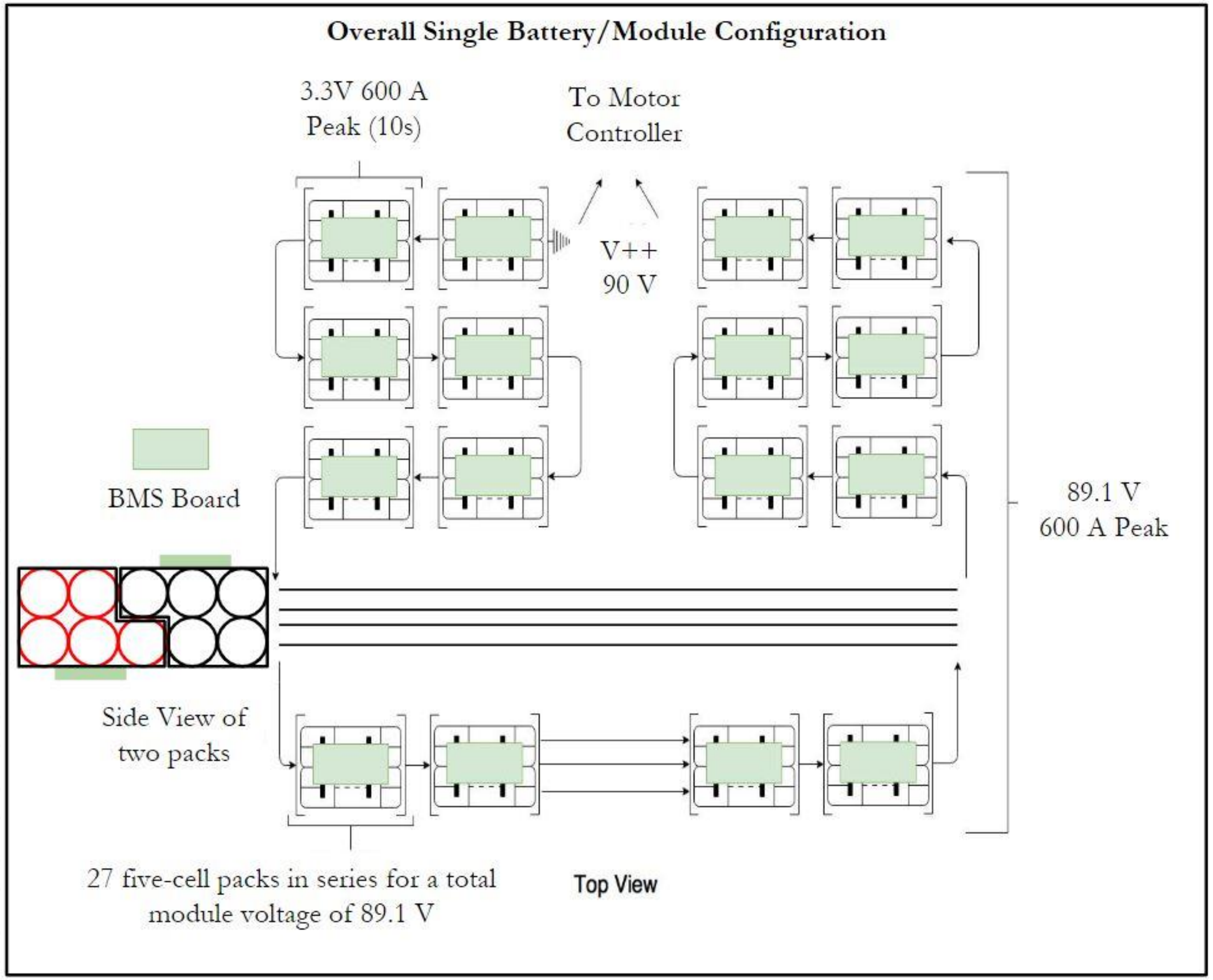
12 V HR9-12 BB Lead Acid Battery

- Total voltage: 12 V
- Total capacity: 8 Ah
- Total stored energy: 96 kJ
- Overall battery dimension: .1588 m x .0650 m x .1001 m

Elithion Battery Management System (BMS)

- Voltage, current, and temperature monitoring
- Passive control over the battery contactors

Total Subsystem Mass: ~42 kg



POWER SYSTEMS: CONSUMPTION

High-Power Consumption Specifications	
Peak Battery Output	53.46 kW
Peak Motor Power	23.00 kW
Peak Output Mechanical Power	22.31 kW
Peak Motor DC Power Input	23.47 kW
Actual Peak Battery Output (Ignoring Losses)	27.62 kW
Motor Power Factor	0.8198
Motor Efficiency	0.98
Drive Efficiency	0.97
Peak Motor Voltage	90 V_{DC}
Peak Motor Current	256 A_{DC}

Low-Power Power Requirements

Component	Number	Power (W)
IMU	1	0.22
Retro-reflective sensor	2	0.3
Rotary Encoder on flywheel	12	0.3
Laser distance sensor	1	1.3
Pressure gauges	4	80
Battery Monitoring System	1	1.8
IR Thermometer CSmicro	3	0.2
Contact Amtherm thermistors	3	0.125
Vibration Sensors	2	0.18
Wireless Sensor Module	1	0.495
Brake caliper linear transducer	4	0.84
Voltage Converter	2	2.16

POWER SYSTEMS: RATIONALE AND TESTING & VALIDATION

Rationale

- The cells will be grouped in packs of four which will be individually insulated by aluminized fabrics to reduce radiation heat transfer to other packs
- Each battery pack will be laced to cooling plates which will use the same cooling system used by the TP motors
- Although the battery can theoretically deliver most of the peak power requirement with only 2 cells in parallel, 5 cells are currently being considered to limit current discharge per cell and subsequently to avoid overheating of the battery.
- The number of cells in parallel is subject to change after discharge testing of the cells is conducted

Testing and Validation

- All tests will be performed in both ambient conditions and in a vacuum environment
- **Impact Test:** Dropping various weights from a certain height to test battery's container strength
- **Short Circuit Test:** Examining the cell behavior during a worst case scenario
- **Rapid Depressurization:** To examine how the cell responds to a sudden change in pressure
- **Load Performance:** Testing at nominal and maximum discharge to confirm true capacity and max temperature difference
- **Thermal Test:** To assess thermal profile while loaded and viable cooling methods if needed

STRUCTURES OVERVIEW: CHASSIS

Design:

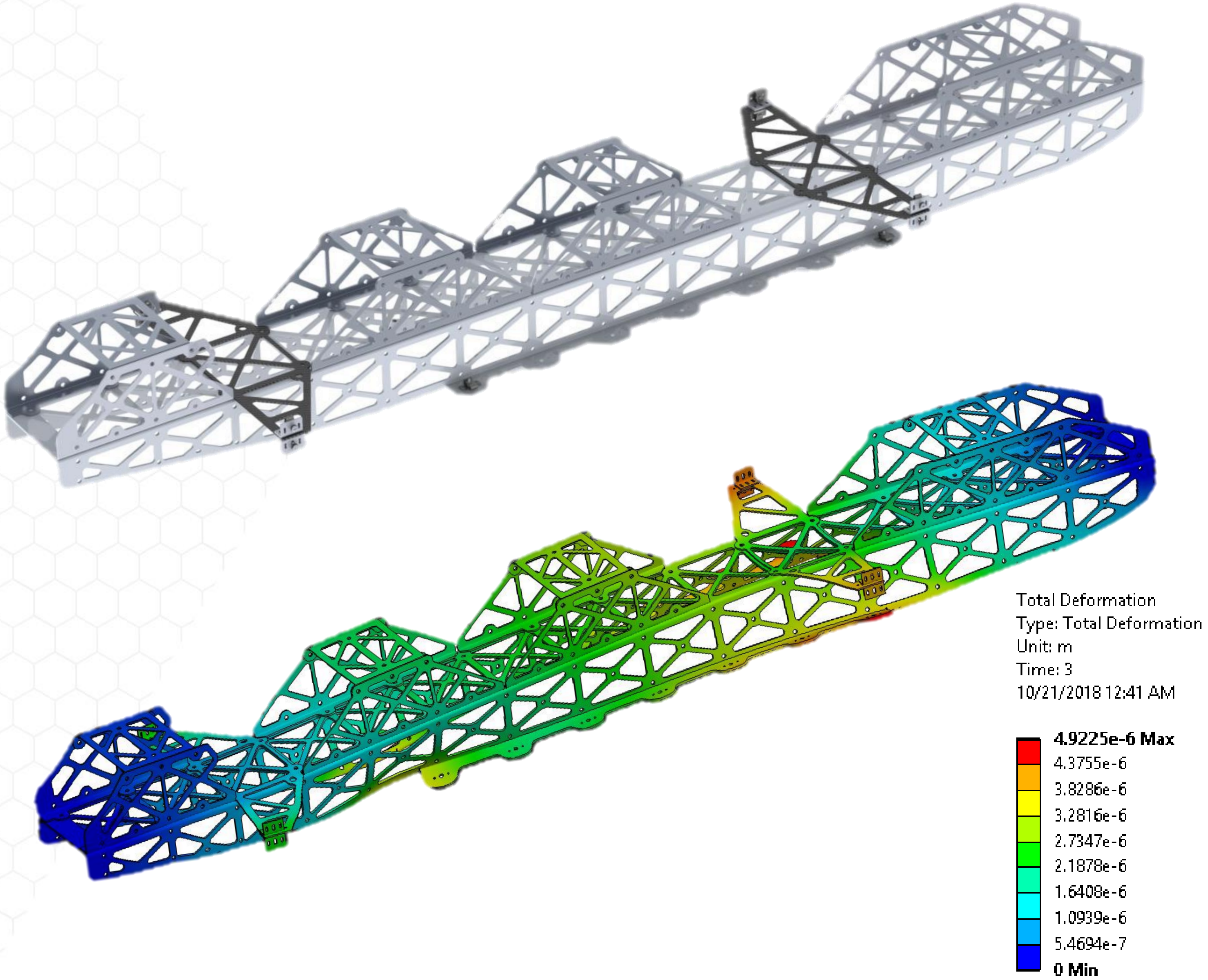
- Acts as the primary structure of the vehicle
- Provides mounting for aeroshell, propulsion, and braking systems

Analysis:

- Brake loading study conducted in ANSYS Mechanical
    - 5 g deceleration study total deformation shown
    - Safety factor of ~8 when braking

Manufacturing:

- All parts are sheet metal or pre-layed up carbon fiber
    - Will be cut on a waterjet and then bent on a brake when necessary (metal parts only)



STRUCTURES OVERVIEW: AEROSHELL

Design:

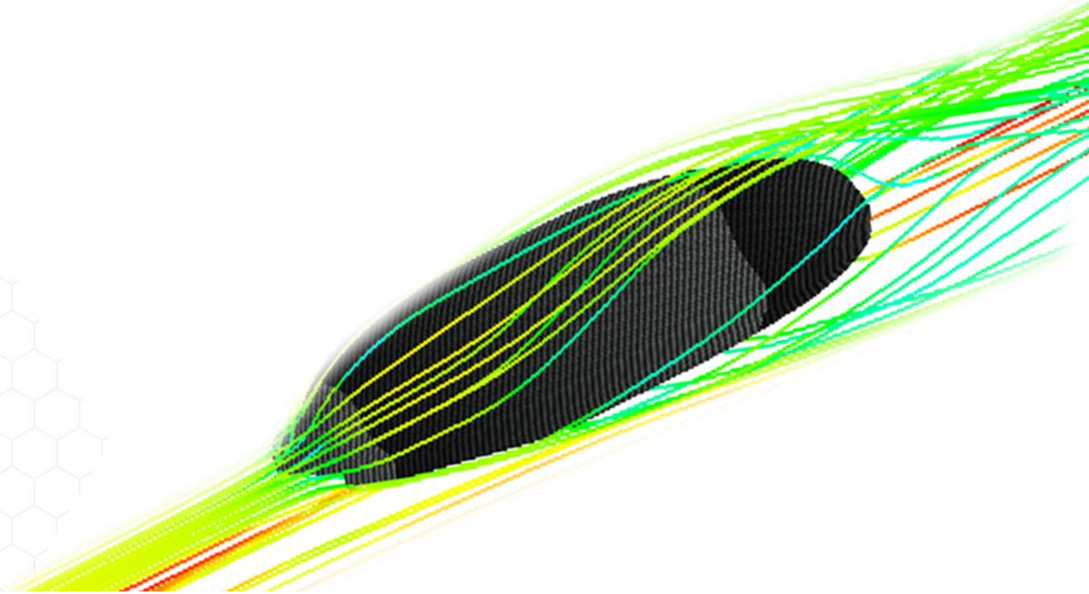
- Prioritizes minimization of front cross-sectional area and mass
- Edge geometry slightly flared to reduce vortex formation

Aerodynamic Analysis:

- Density-based computational fluid dynamics study performed
  - Accounts for compressibility effects
  - 500,000 mesh element viscous Spalart-Allmaras turbulence model accounts for possible flow separation

Manufacturing:

- Wet carbon fiber layup with 4 layers of 2x2 twill
  - MDF mold created on 3-axis CNC



Geometric Parameters	Value
Overall Length (m)	1.7
Overall Width (m)	0.38
Overall Height (m)	0.38
Shell Thickness (mm)	1.011
Cross Sectional Area (m^2)	0.0743

Aerodynamic Parameters	Value
Coefficient of Drag	0.147
Coefficient of Lift	0.0401
Tested Density (kg/m^3)	0.111
Tested Mach Number	0.441
Tested Static Temp. (K)	298

STABILITY

Design

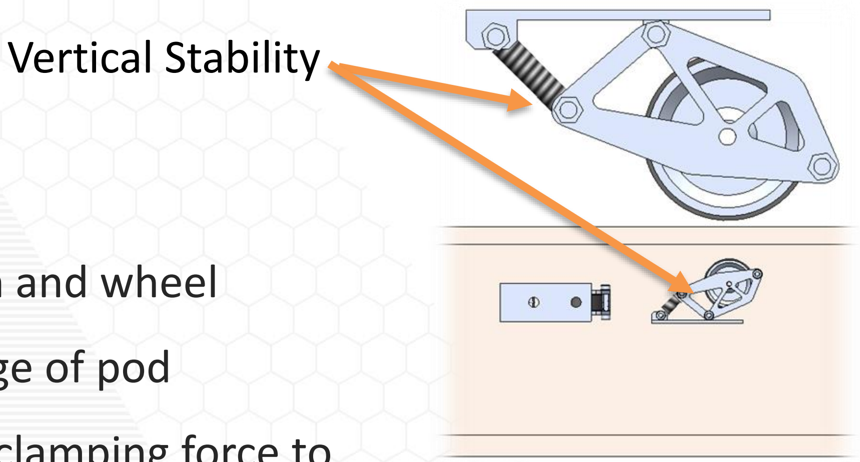
- Rocker connected to a spring damper system and wheel
- Stability system optimized for frequency range of pod
- Rocker system underneath the track applies clamping force to prevent slippage on driven wheels
- Lateral stability system helps stabilize pod along yaw axis

Testing:

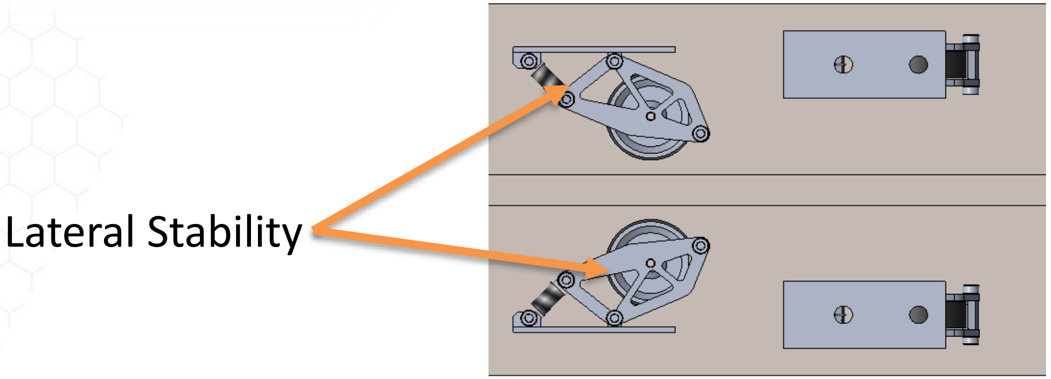
- Pod simulated with gaps on the track and alignment deflections
- Physical testing will be performed by spinning an aluminum disk with a motor and applying stability wheels to the disk

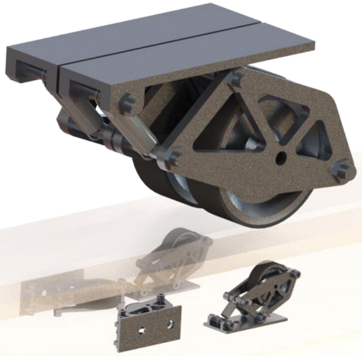
Total Subsystem Mass: 2.5 kg

View from Side



View from Below





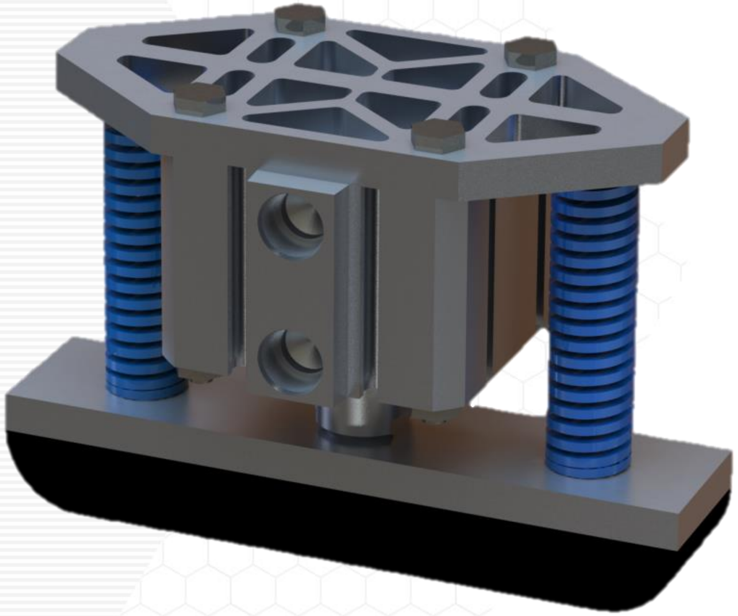
BRAKING AND PRESSURE SYSTEM

Brakes:

- Friction Material: Non-Asbestos Organic
- Coefficient of Friction: 0.55
- Braking Force: 5000 N
- Vehicle Deceleration: 5 g

Pneumatics:

- Cylinder Bore: 38.1 mm
- Operating Pressure: 0.921 MPa
- Air Tank Volume: 1.90 L

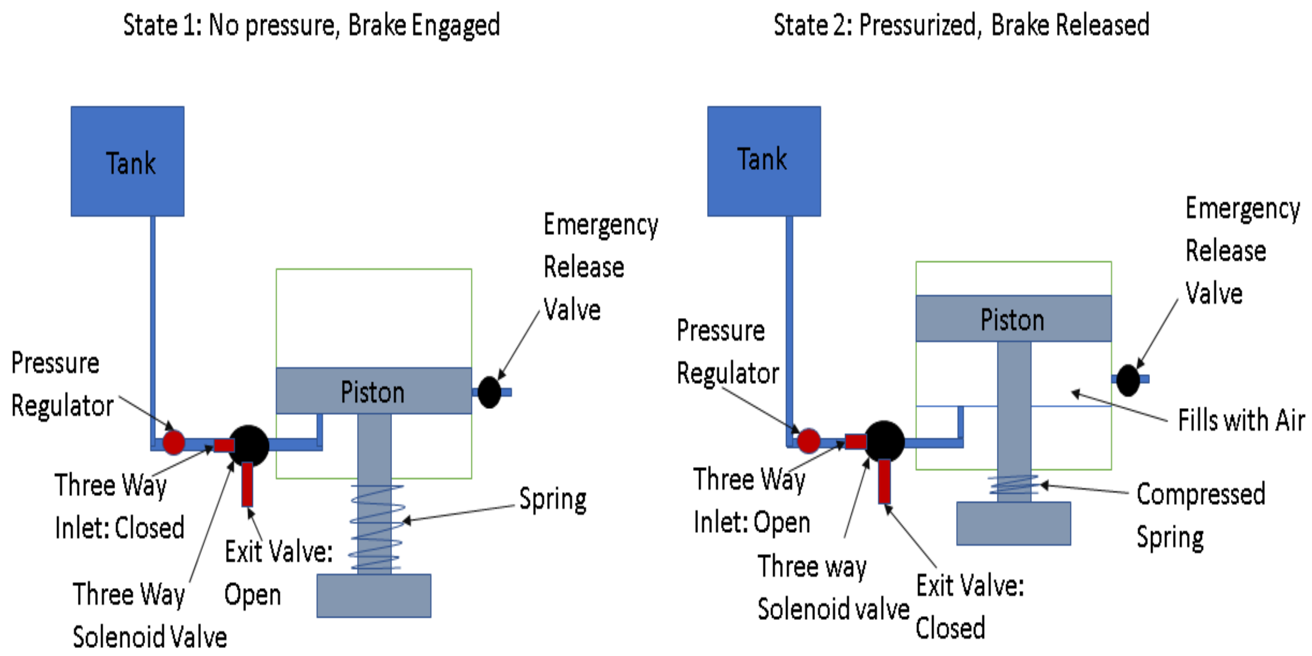


Component	Mass (kg)	Quantity	Total Component Mass (kg)
Cylinder	0.20	12	2.4
Spring	0.09	24	2.18
Air Tank	2.36	1	2.36
Brake Pad	0.08	12	0.96
Total Subsystem Mass (kg)			**7.9**

BRAKING AND PRESSURE SYSTEM

Pneumatics System Overview:

- Air tank to be pressurized using an external compressor before loading the pod onto the track
- Brakes are retracted when a 0.921 MPa is maintained
- Brakes are fully engaged when brake cylinder is fully depressurized
- An electronically-controlled valve regulates braking force by venting air to decrease cylinder pressure as needed
- In case of failure, emergency valve will be opened, applying brakes to track



BRAKING AND PRESSURE SYSTEM

Rationale:

- Pneumatic spring applied brakes allows for a fail-safe in case of power failure. The cylinder needs to be pressurized to retract brakes, so if any failure occurs, the brakes will automatically be engaged after the cylinder is depressurized by an open valve. The braking force can also be adjusted by the amount of pressure present in the cylinders.
- 12 brakes were chosen so that the pod would have 6 brakes on the top of the rail and 6 brakes on the bottom of the rail to provide braking force that is symmetric. 12 brakes are needed to keep the pressure requirements at a reasonable level and at a size suitable for the track and chassis.
- A non-asbestos organic friction material was chosen to avoid damaging the track when braking. The leading edge of the brake pads will be rounded off to better handle surface deviations on the track.
- The entire braking system has been designed with minimal custom-made parts to maximize ease of manufacture.

Testing and Validation Plans:

- A test rig will be constructed that will spin an aluminum flywheel up to a specified speed, at which point a brake situated on top of the disk will apply a braking force until the disk comes to a stop
- This test rig will provide experimental data regarding wear rate, heating, coefficient of friction, and braking force as well as allow us to practically test electronic braking controls. Testing will be conducted in an ambient and low-pressure environment.

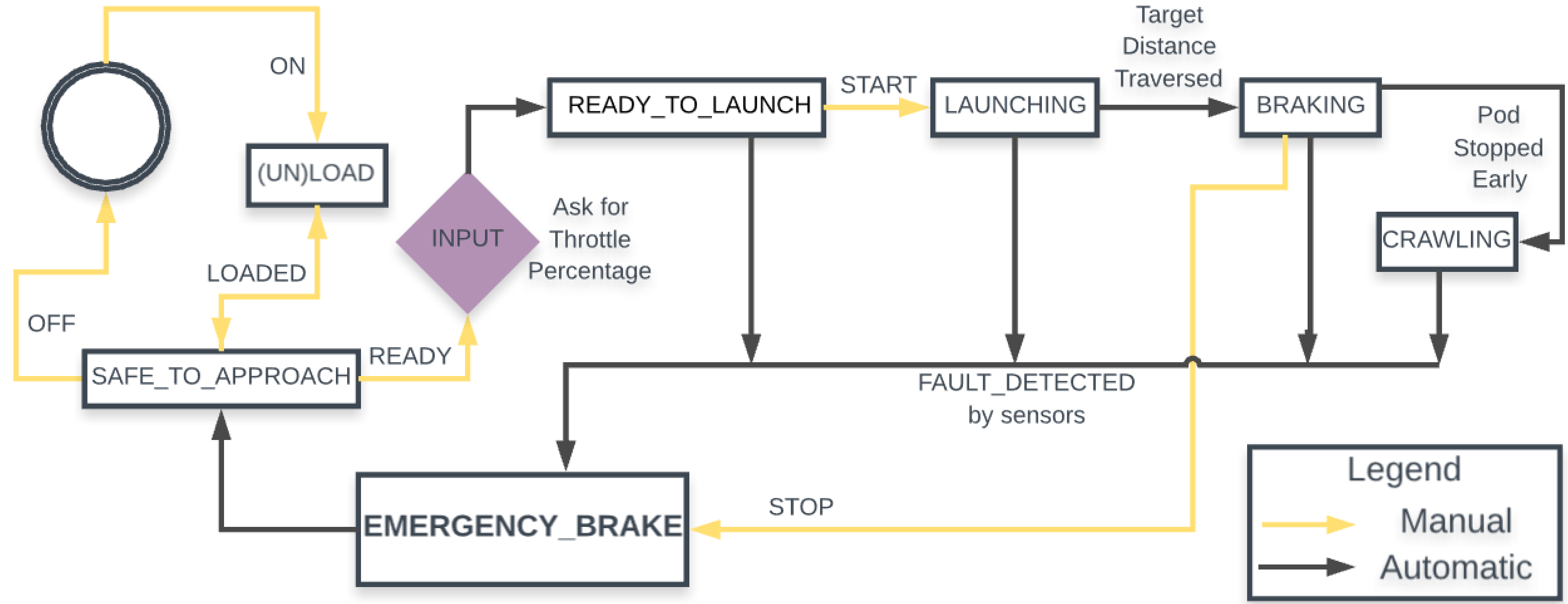
NAVIGATION AND CONTROL: SUMMARY

State	Condition/Transitions	High Power	Throttle	Brakes	Low Power
OFF		OFF	0%	100%	OFF
LOAD/UNLOAD	(“GO” is pressed)	OFF	0%	0%	ON
SAFE TO APPROACH	("LOADED" is pressed)	ON	0%	100%	ON
READY TO LAUNCH	Input for Throttle	ON	0%	0%	ON
LAUNCHING	("START" is pressed)	ON	INPUT%	0%	ON
	//runs until velocity x is achieved or if desired distance is reached.				
BRAKING	(pod at y distance before end)	ON	0%	100%	ON
	//runs until velocity = 0				
CRAWLING	(pod stopped early)	ON	20%	0%	ON
	//runs until finish line is reached				
EMERGENCY BRAKE	if (Temp on a circuit exceeds <a temp>	ON	0%	100%	ON
	OR Temp on battery exceeds <b temp>				
	OR Temp on motor exceeds <c temp>				
	OR Vibration exceeds <d amplitude>				
	OR Network Disconnect)				
	then FAULT_DETECTED = true;				

Fiducial Sensors

- Inertial Measurement Unit
- Retroreflective Sensors
- Rotary Encoders
- Motor Encoders
- Laser distance sensor

NAVIGATION AND CONTROL: CONTROL STATE DIAGRAM



NAVIGATION AND CONTROL: RATIONALE

Sensor(s)	Data	Comments
Inertial Measurement Unit	Acceleration	Two, located at front and back of pod to minimize error by comparing two data sets.
		Acceleration can also be used to calculate velocity
		Consists of Gyroscope and Accelerometer
Rotary Encoder on flywheel	Velocity	One on the non-powered flywheel at center of mass to calculate velocity. Compare data with Motor Encoder to get a small interval in which true velocity of the pod lies, due to slippage between the track and wheels.
Motor Encoder	Velocity	On each direct drive motor system for 4x independent data collection.
Retroreflective sensor	Distance	Two, on sides of pod (will function as "eyes" of pod).
		3 kHz+ sampling rate to account for high speed at which the pod moves, and taking into account thickness of retroreflective tape to ensure in the worst case scenario, at least one data collection point would cover each strip
Laser distance sensor	Distance	To determine distance from pod to end of the tube, within 100 ft.
Temperature sensors	Temperature	Infrared Sensor: ThermoMETER CSmicro
		Contact Sensor: Amtherm Thermistors
Power consumption monitor	Power for Main Power System	Shunt for Main Power System
Vibration Sensors	Gyroscope fluctuations	Changes in the Gyroscope correspond to changes in the Amplitude of Vibration, which measures pod stability.
Pressure Transducer	Air Pressure	Monitors pressure in air tanks and brakes.

NAVIGATION AND CONTROL: TESTING & VALIDATION

Sensor Testing

- Individual sensor testing and calibration out of the box to ensure components meet requirements
  - Simulated environment testing for retroreflective sensors, rotary encoders, and IMU to ensure they operate reliably at pod's max speed
  - All tests performed in both ambient conditions and in a vacuum environment

Control Testing

- Ensure proper state transitions with simulated and real sensor data
- Simulated component failures
- PCB/controller reliability testing in vacuum environment and at expected running temperatures

PROPULSION SYSTEM

Motor: TP Power TP-100 X 4 (Direct Drive)

- Power (Continuous/Peak): 12kW/23kW
- Max RPM: 25000
- Torque: 8.2Nm
- Acceleration: 0.71 g
- Voltage: 90V
- Current: 256A

Motor Controller: Flier 22S 350A ESC

Wheels:

- Diameter: 10.24 cm
- Material: Aluminum Rim, .26 cm polyurethane lining
- Coefficient of Friction: 0.76

Component	Mass (kg)	Quantity	Total Component Mass (kg)
Motor	2.93	4	11.7
Wheel	0.46	4	1.8
Cooling System	11	1	11
Motor Controller	0.54	4	2.2
Total Subsystem Mass (kg)			**26.7**

PROPULSION SYSTEM

Rationale:

- Direct drive enables us to reduce mass from belt drives, improve power transmission efficiency, simplify design, and reduce wheel size.
- Direct drive also increases manufacturability since a complex belt drive system will not be necessary.
- The TP 100 Motor was chosen because of its high rpm, high power output, low mass, and optimum max current/voltage.

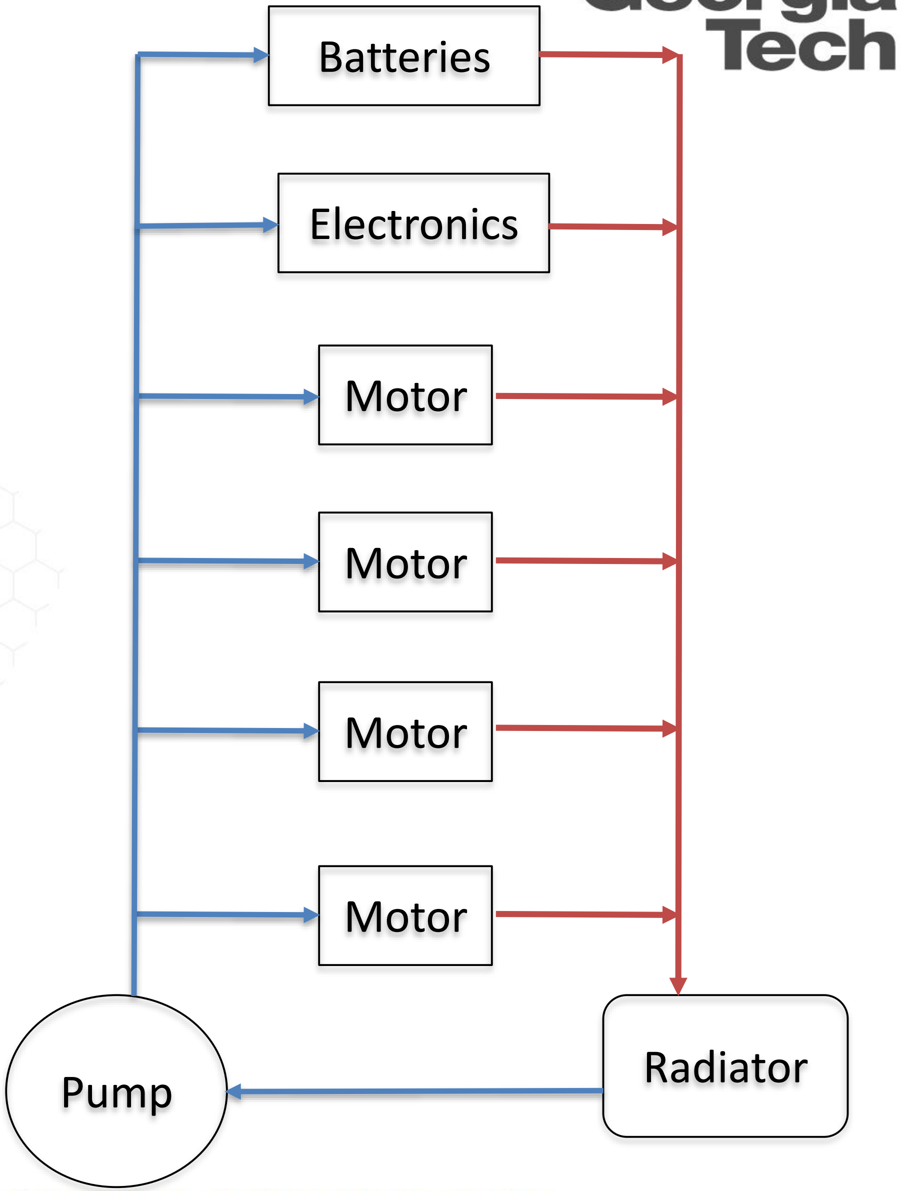
Testing and Validation Plans:

- To determine the viability of braking using the motors, a rheostatic braking test rig will be constructed using a motor and an aluminum flywheel. The wheel will be spun by the motor up to the max motor rpm, and then the deceleration of the flywheel will be measured while the motor is unpowered, allowing braking force to be calculated versus velocity.
- To test heating of motors in a low-pressure environment, we will attach a thermocouple to the motor and run it at max power in different pressures for 30 seconds to model a heat vs. pressure curve.

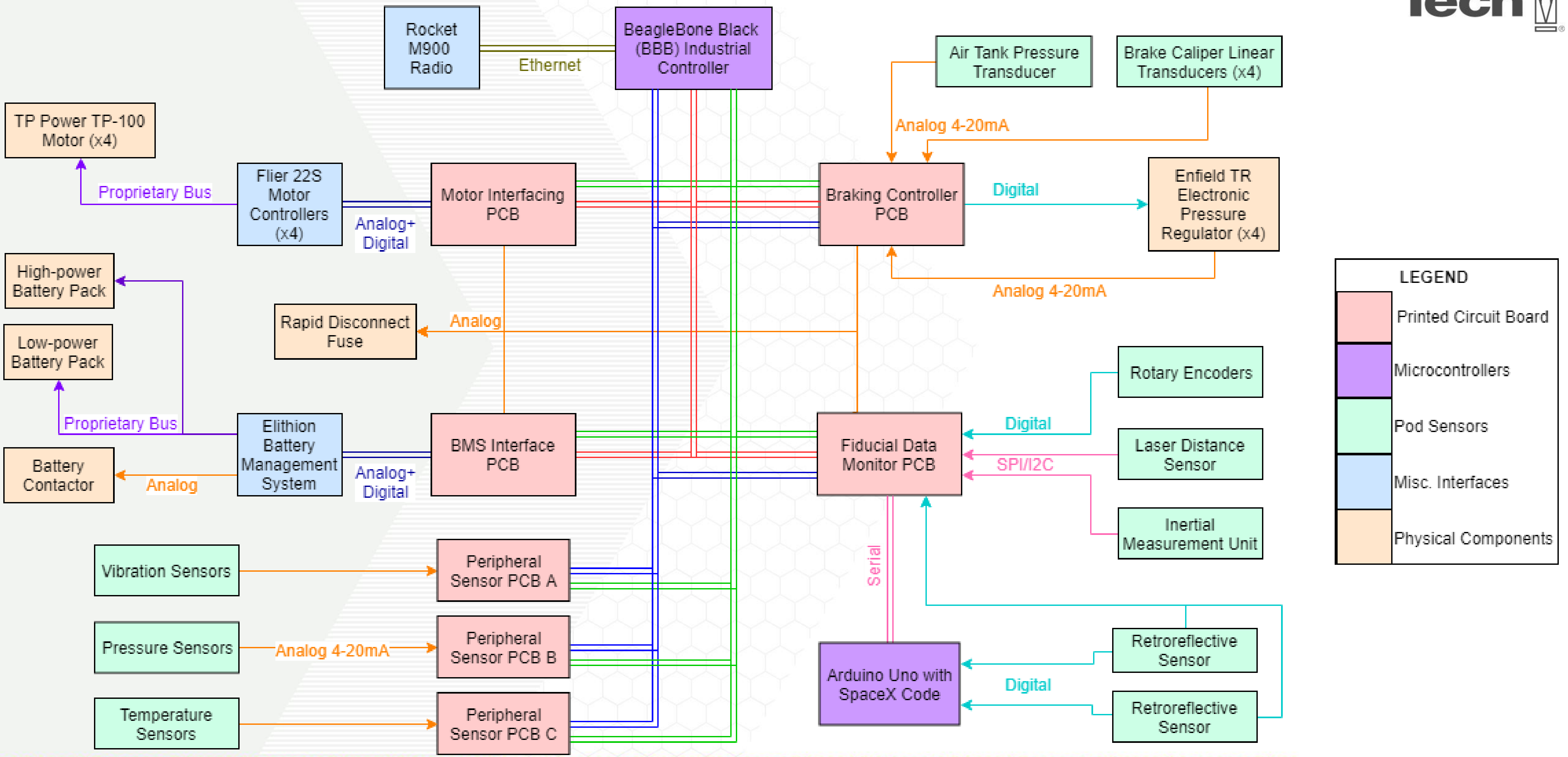
COOLING SYSTEM

System Overview:

- Each TP 100 motor includes a water-cooling jacket through which water will be pumped
  - Using four smaller motors rather than one large motor reduces the heat produced per motor, thereby reducing the risk of overheating
- Batteries and other electronics will also be water-cooled via a chilling plate
- Pump Flow Rate: 12 L/min



ELECTRONICS SYSTEMS



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ELECTRONICS SYSTEM: RATIONALE

Motor Interfacing PCB

- Relays critical control commands to motor controllers, feeds back motor encoder data to other PCBs on CAN bus.

Braking Controller PCB

- Forwards pressure setpoints to pressure regulators and monitors regulator stability for a fault state.
- Monitors air tank pressure for safety, linear transducers for brake operation verification.

Fiducial Data Monitor PCB

- Reads in from retroreflective sensors on digital interrupts to measure total distance travelled using tape.
- Ensures redundancy with rotary encoder data for worst-case distance, IMU for instant acceleration and velocity.
- Equipped with laser distance sensor to ensure good distance accuracy for final 100 feet of run.

Battery Monitoring Interface PCB

- Interfaces with Elithion battery management system to read battery pack current, voltage and temperature data.
- Can effect shutdown if power loss is imminent, batteries are overdrawn, or thermal runaway is detected.

Peripheral Sensor PCBs

- Localized PCBs at sensor points-of-use, used to relay non-critical sensor information on CAN bus.
- Sensor information can be used to change drivetrain processes if data collected is outside safe thresholds.

HAZARDOUS SYSTEMS

Pressure Systems:

- Max Pressure Rating: 1.034 MPa
- Planned Operating Pressure: 0.921 MPa
- Stored Energy in Air Tank: 12.2 kJ
- Emergency release valve will ensure pressure in system does not exceed 1.034 MPa

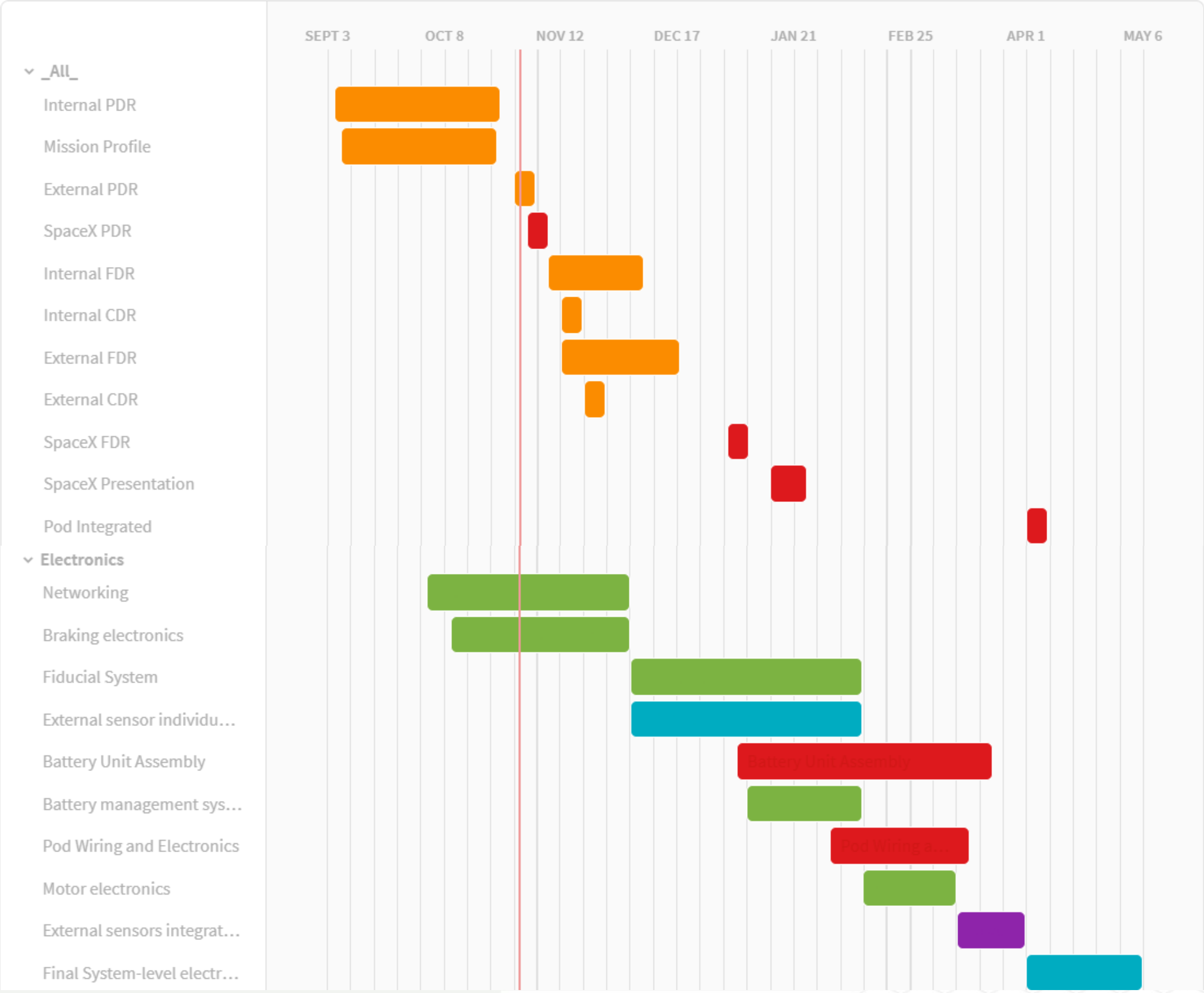
Batteries:

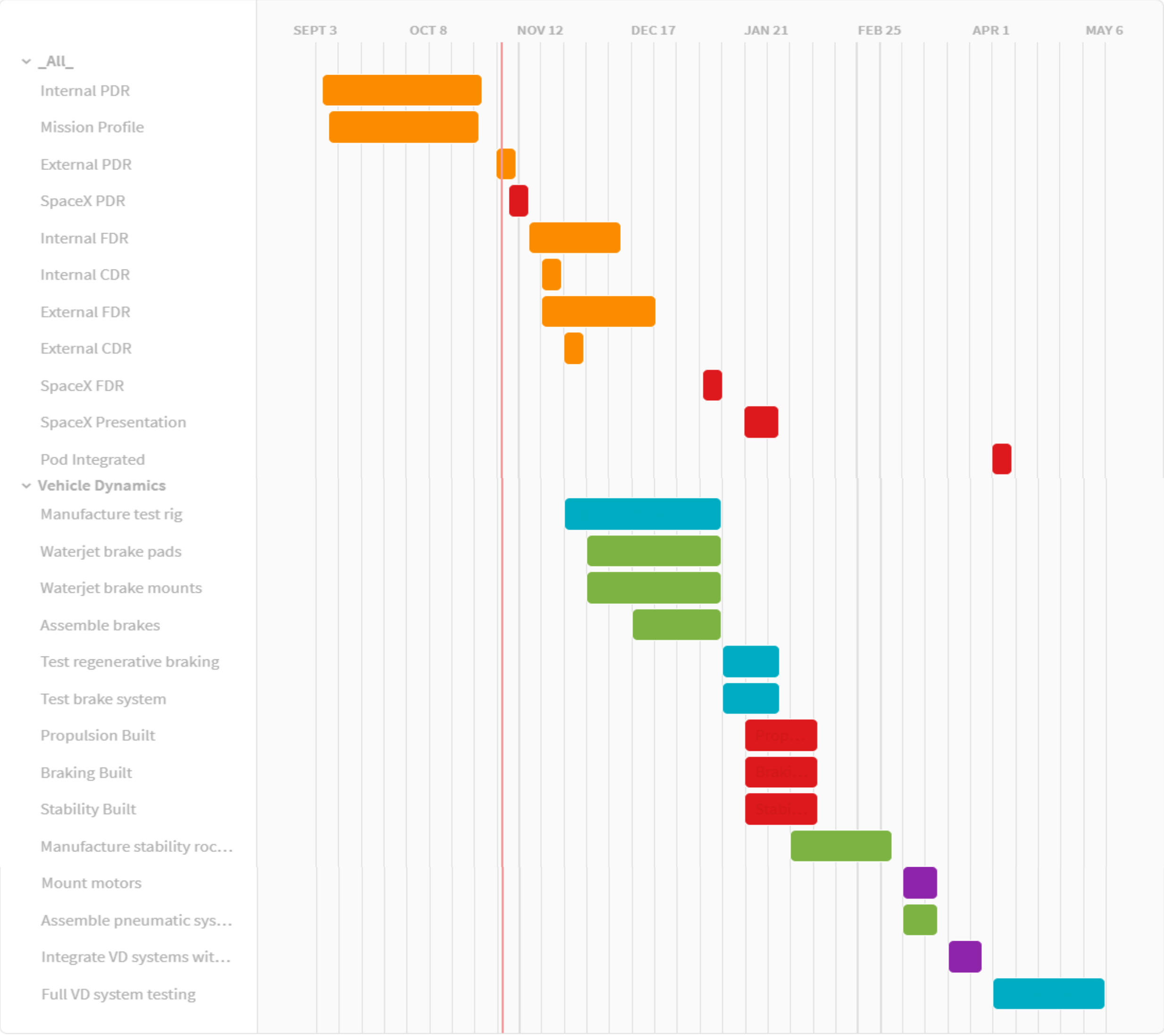
- High Power Circuit Stored Energy: 17.84 MJ
- Low Power Circuit Stored Energy: 96 kJ
- High power circuit managed by an Elithion Battery Management System

ANTICIPATED CHALLENGES

- **Hardware-Firmware Compatibility:** Using a variety of custom and off-the-shelf hardware and firmware will create a system that is complex to debug
  - Integration testing will be done along the way to ensure each electronic subsystem works in the overall pod before completing the next subsystem's electronics
- **Stability:** Ensuring pod stability during braking phase will be difficult due to the high forces involved
  - Data acquired through rigorous simulation will be combined with physical data from the vehicle dynamics test rig to confirm that the pod will brake smoothly
- **Structural Analysis:** Structural analysis will require significant computing resources
  - An analysis specific desktop computer is being sponsored by the School of Aerospace Engineering
- **Thermal Testing:** Due to the low-pressure environment of the track, the cooling system will need to be thoroughly validated to ensure that no system overheats during the run
  - Vehicle components will be tested at low pressures to ensure that temperature increases are within allowable limits

DESIGN, BUILD, TEST TIMELINE:
VEHICLE DYNAMICS AND ELECTRONICS





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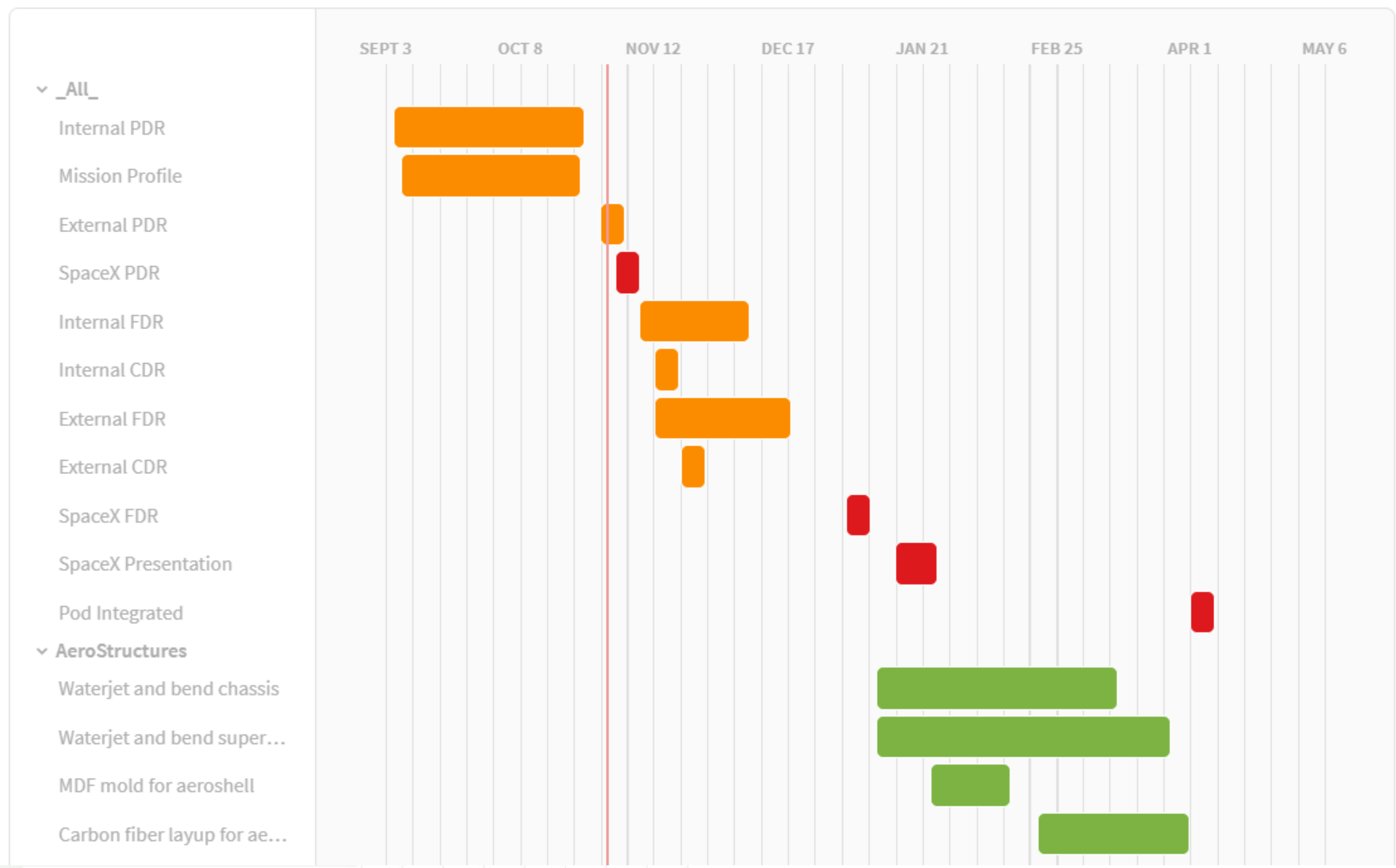
DESIGN, BUILD, TEST TIMELINE: AEROSTRUCTURES



FUNDING PLAN AND TIMELINE

Overall budget for full-vehicle manufacture/integration: Approximately $27,000

Sources:

- Georgia Tech Student Government Association (SGA): $10,000-$15,000 expected
- Corporate Sponsors: $15,000-$20,000 expected
- GT School of Aerospace Engineering: Ancillary Support (lab space, compute resources)

Phase	Timeline	Description (of components to be procured)	Funds Allocated	Source(s)
Phase 1	8/2018-9/2018	Initial electronics and communications products Propulsion system and motors	$4,000	SGA
Phase 2	10/2018-11/2018	Metal and composite materials for structures Circuit boards and pressure system electronics	$8,000	SGA
Phase 3	12/2018-7/2019	Dynamical and fluid system components Power system, controllers, and final electronics assemblies Full vehicle integration	$15,000	SGA Corporate Sponsors