ODDITY Preliminary Design Review

Members:
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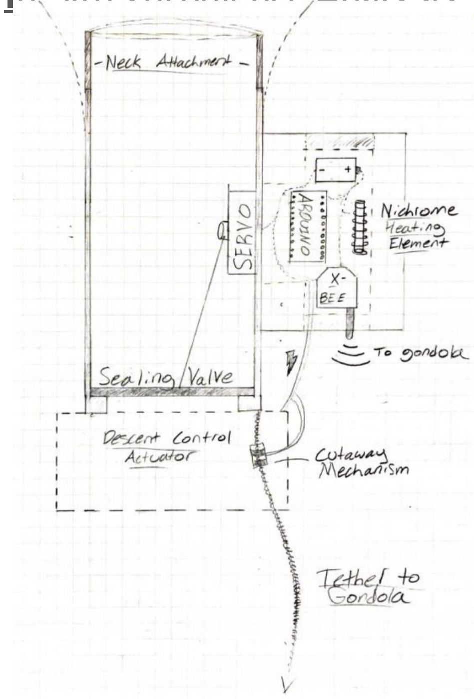
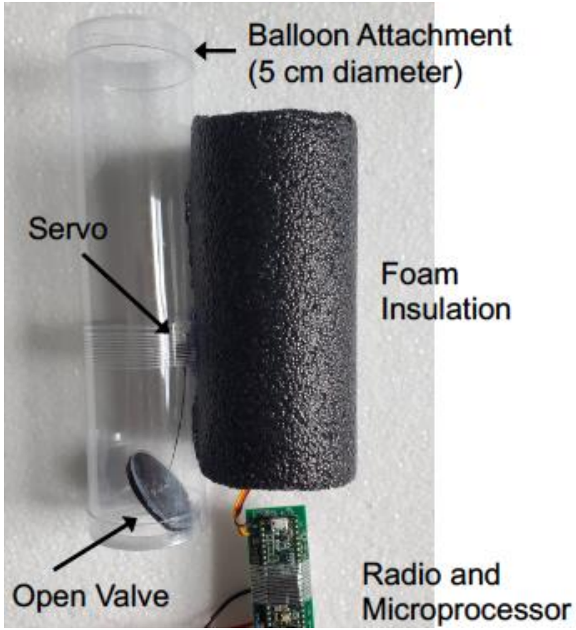
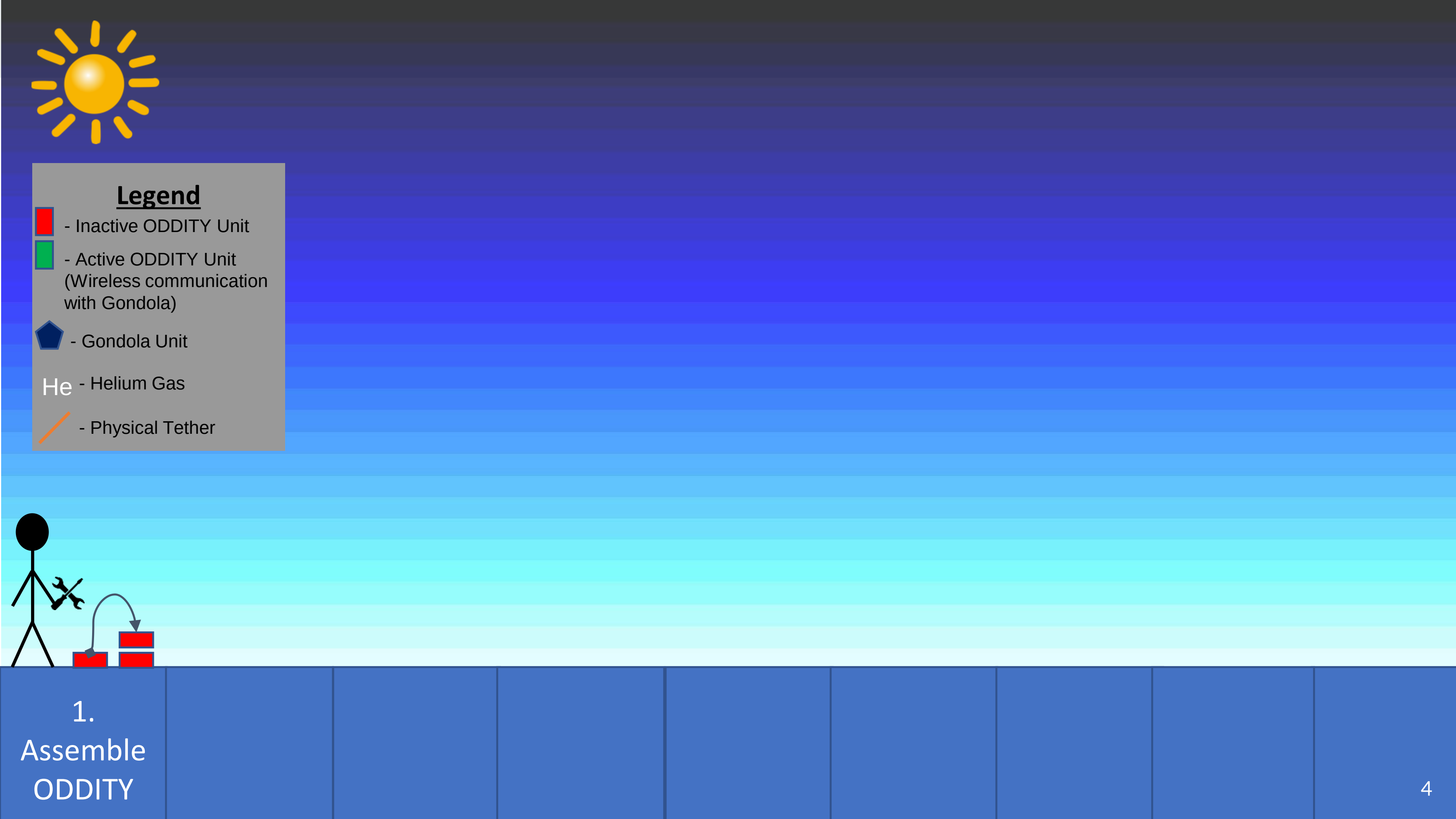
What is ODDITY?

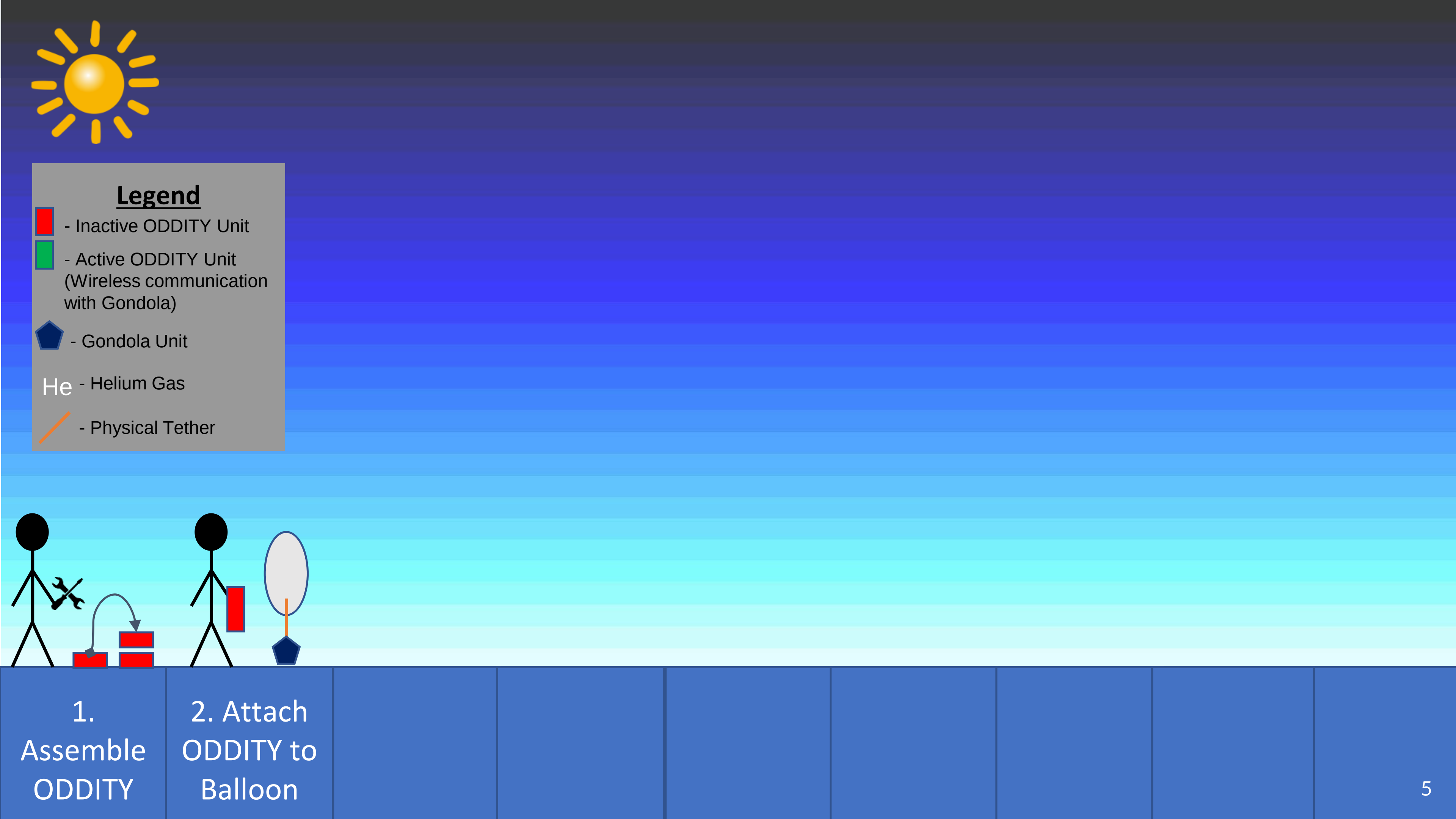
ODDITY: Optimal Descent Device for In-Situ Turbulence AnalYsis





Contents


Legend
- Inactive ODDITY Unit
- Active ODDITY Unit (Wireless communication with Gondola)
- Gondola Unit
He - Helium Gas
- Physical Tether
1. Assemble ODDITY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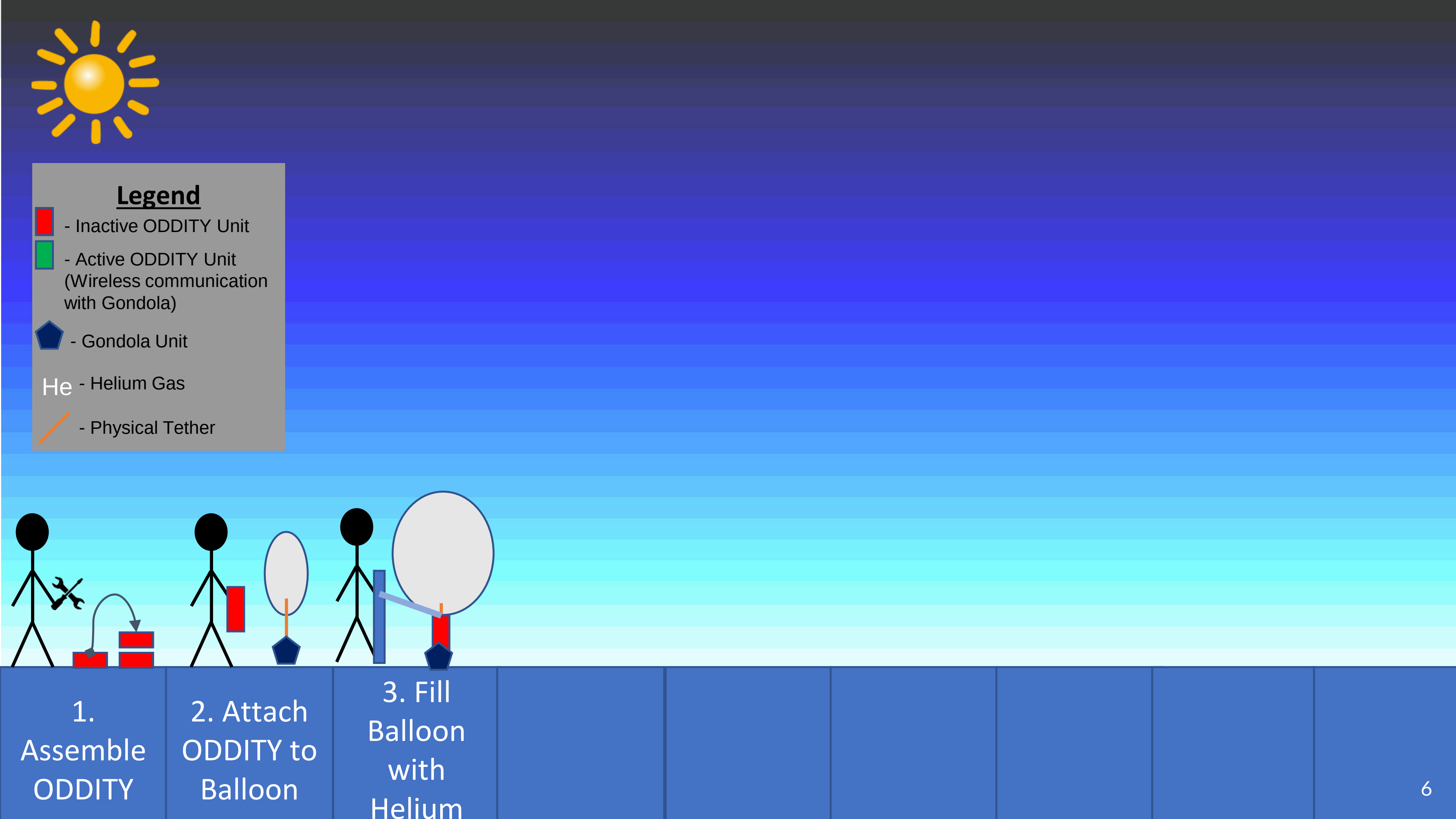
2. Attach ODDITY to Balloon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1. Assemble ODDITY
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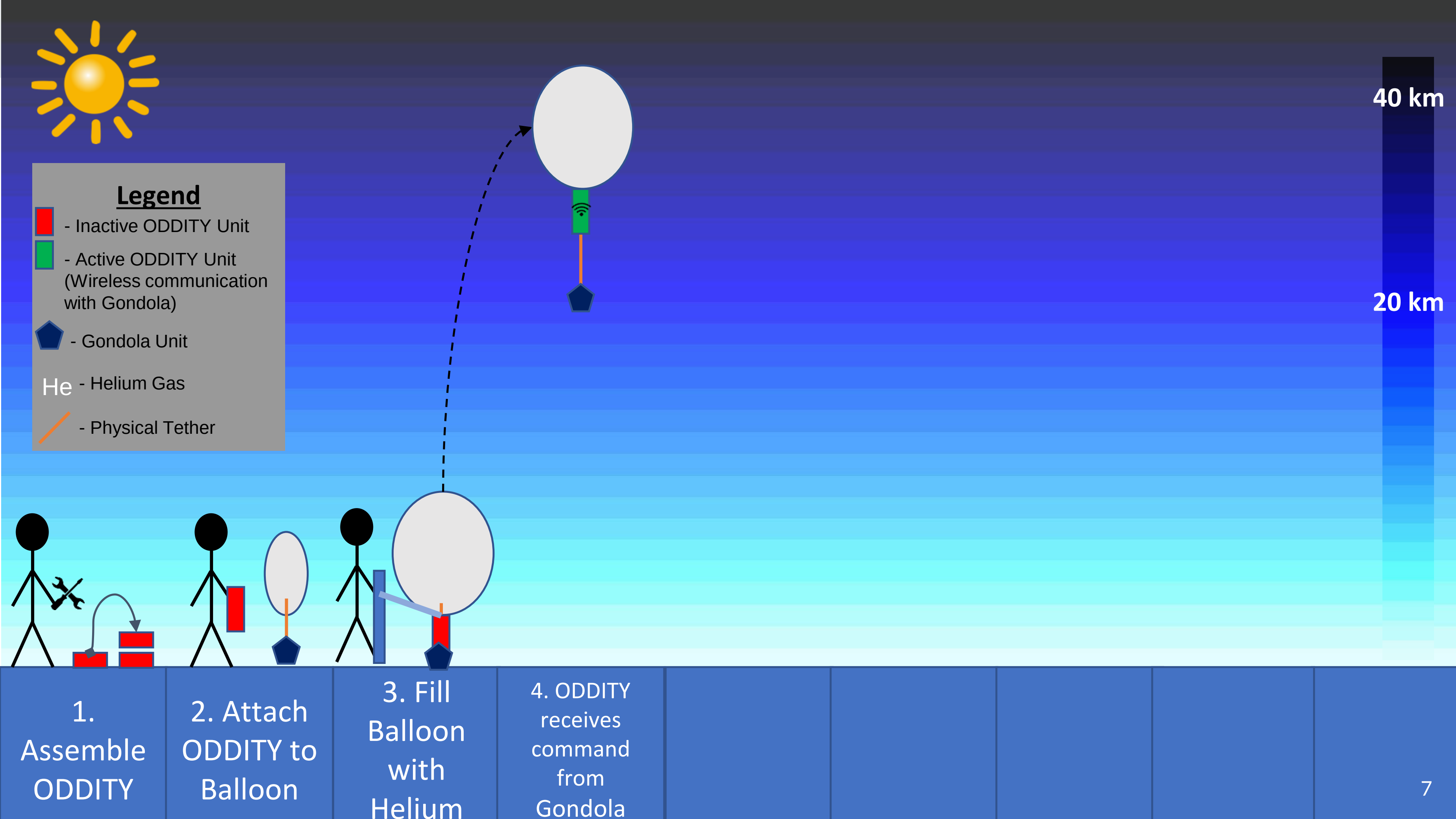
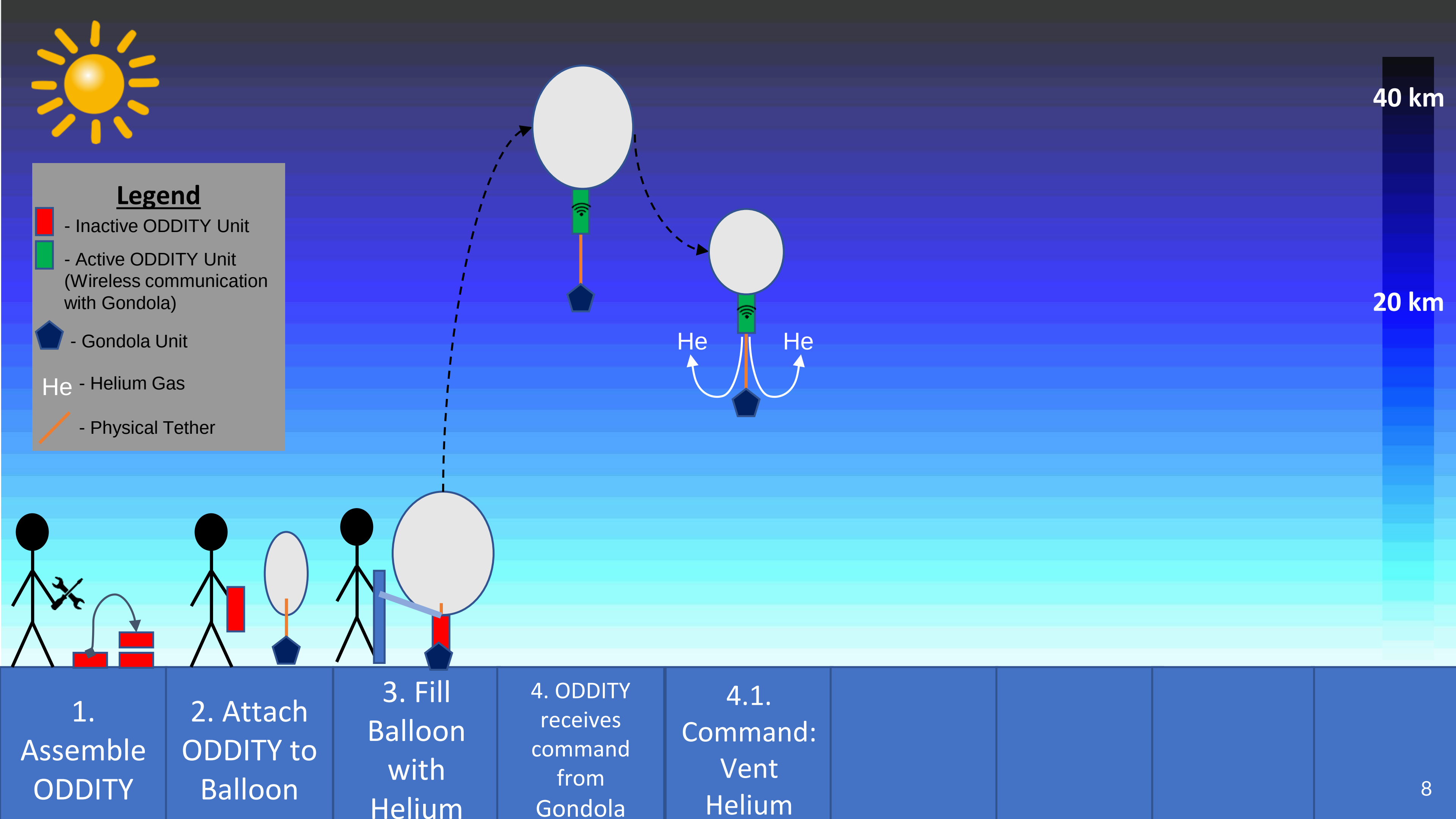
3. Fill Balloon with Helium



Legend
- Inactive ODDITY Unit
- Active ODDITY Unit (Wireless communication with Gondola)
- Gondola Unit
He - Helium Gas
- Physical Tether
40 km
20 km
1. Assemble ODDITY
2. Attach ODDITY to Balloon
3. Fill Balloon with Helium
4. ODDITY receives command from Gondola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1. Assemble ODDITY
2. Attach ODDITY to Balloon
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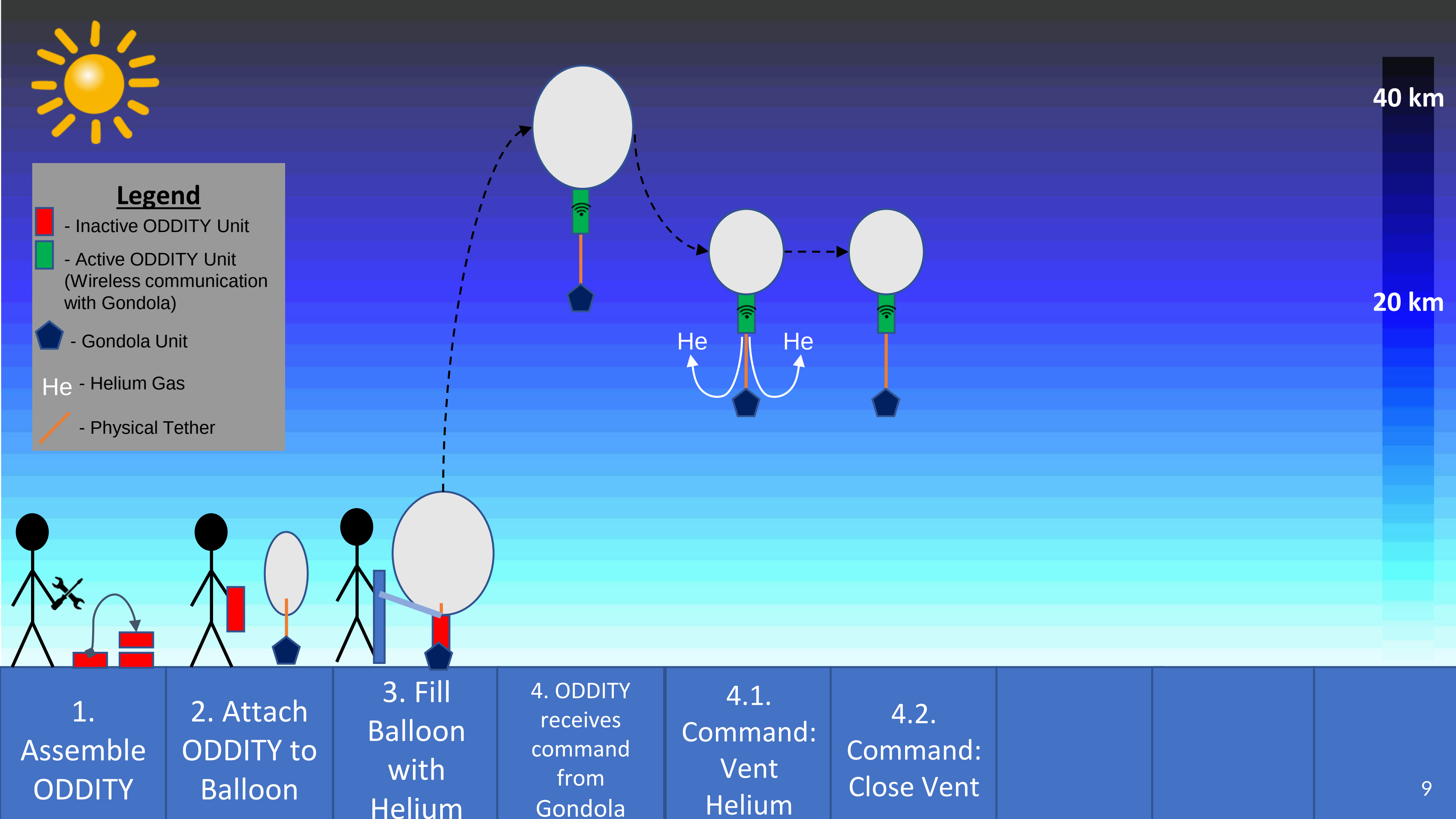
4. ODDITY receives command from Gondola
4.1. Command: Vent Helium



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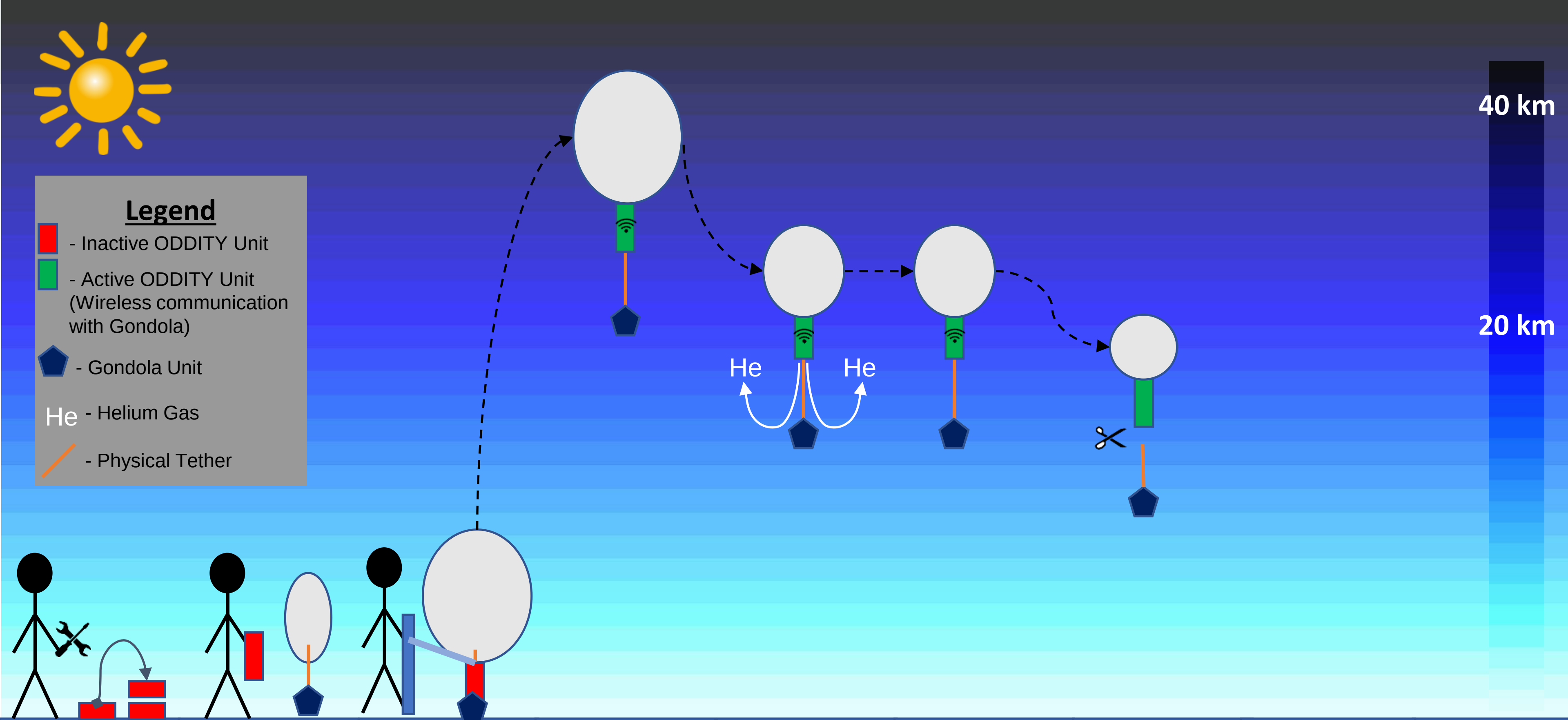
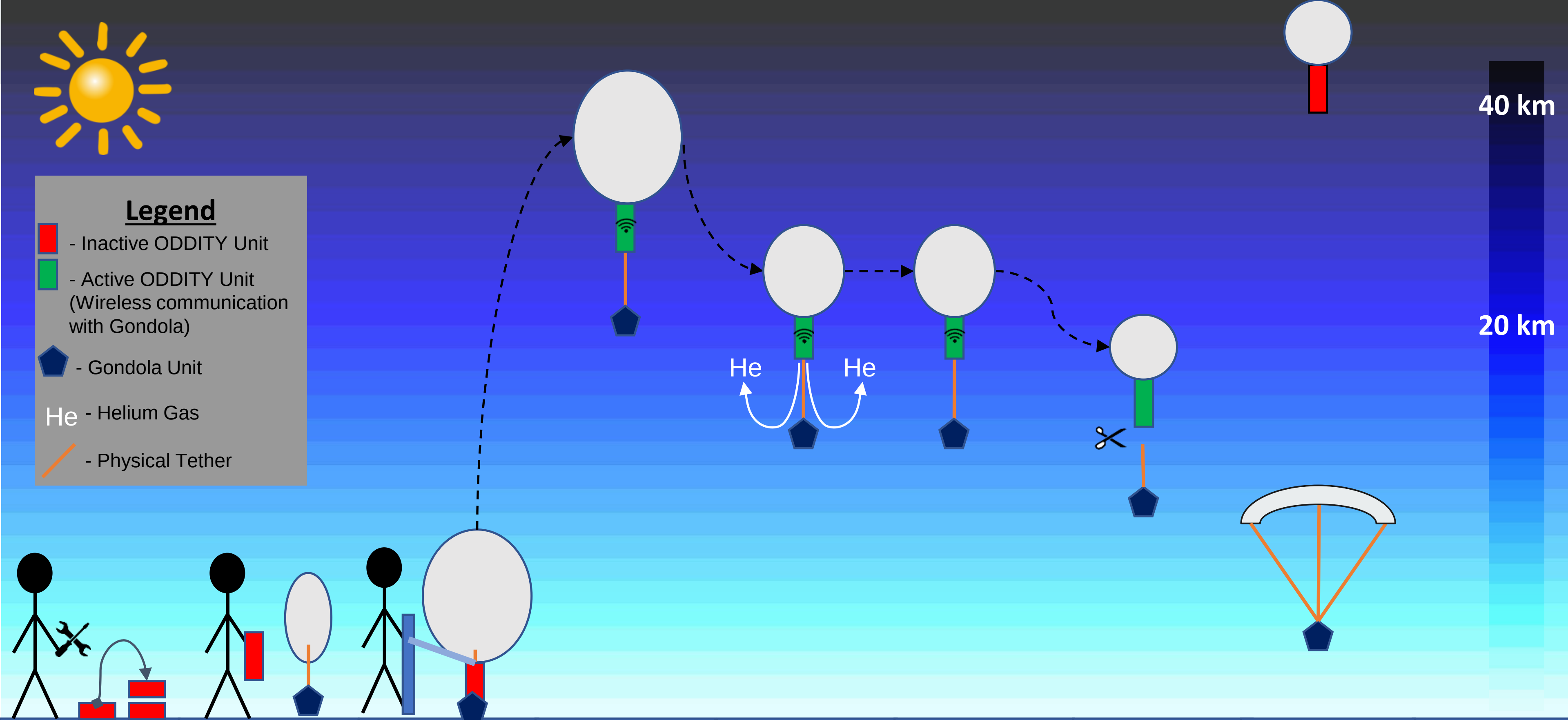
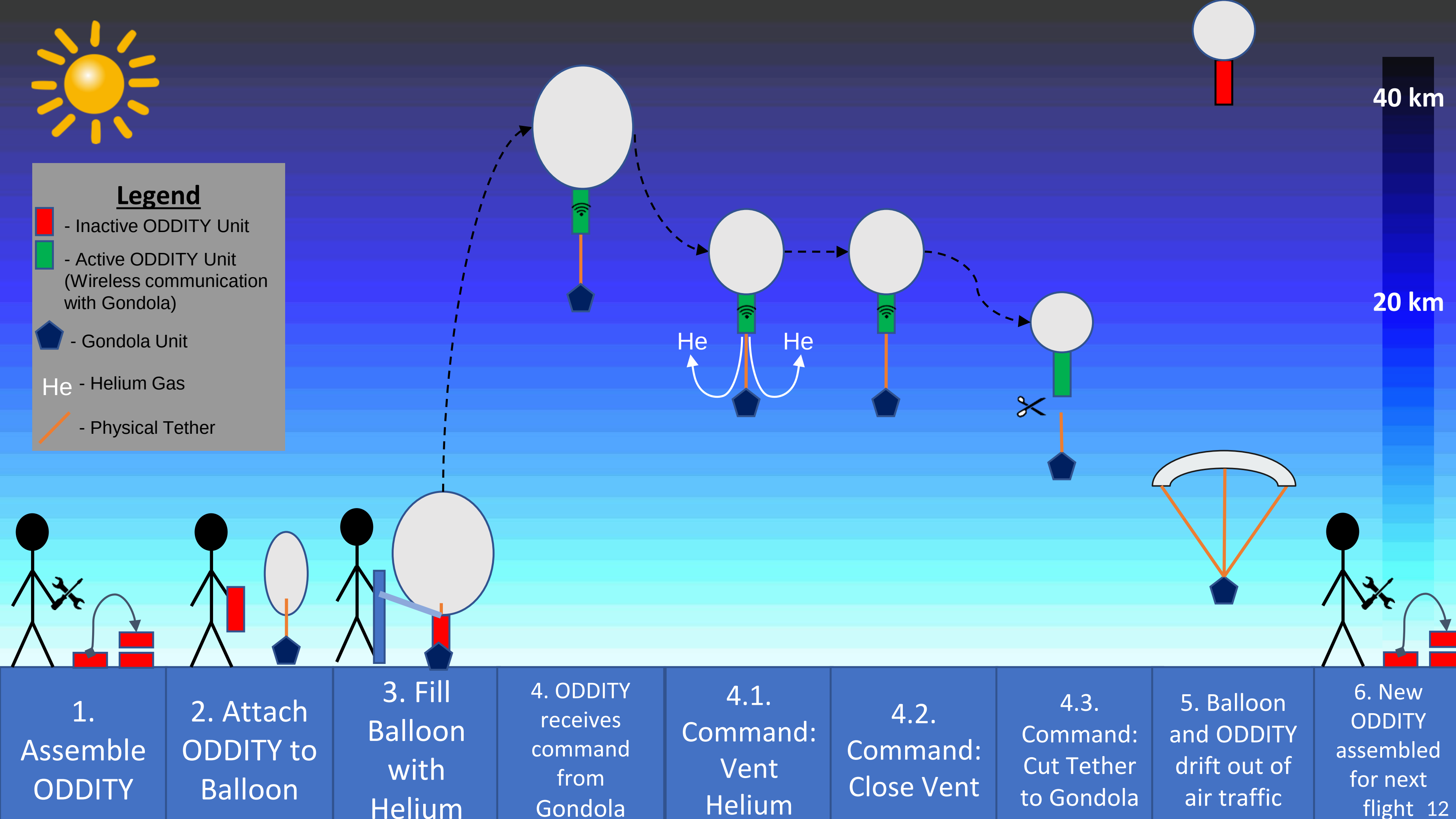
1. Assemble ODDITY
2. Attach ODDITY to Balloon
3. Fill Balloon with Helium
4. ODDITY receives command from Gondola
4.1. Command: Vent Helium
4.2. Command: Close Vent



1. Assemble ODDITY	2. Attach ODDITY to Balloon	3. Fill Balloon with Helium	4. ODDITY receives command from Gondola	4.1. Command: Vent Helium	4.2. Command: Close Vent	4.3. Command: Cut Tether to Gondola		



1. Assemble ODDITY	2. Attach ODDITY to Balloon	3. Fill Balloon with Helium	4. ODDITY receives command from Gondola	4.1. Command: Vent Helium	4.2. Command: Close Vent	4.3. Command: Cut Tether to Gondola	5. Balloon and ODDITY drift out of air traffic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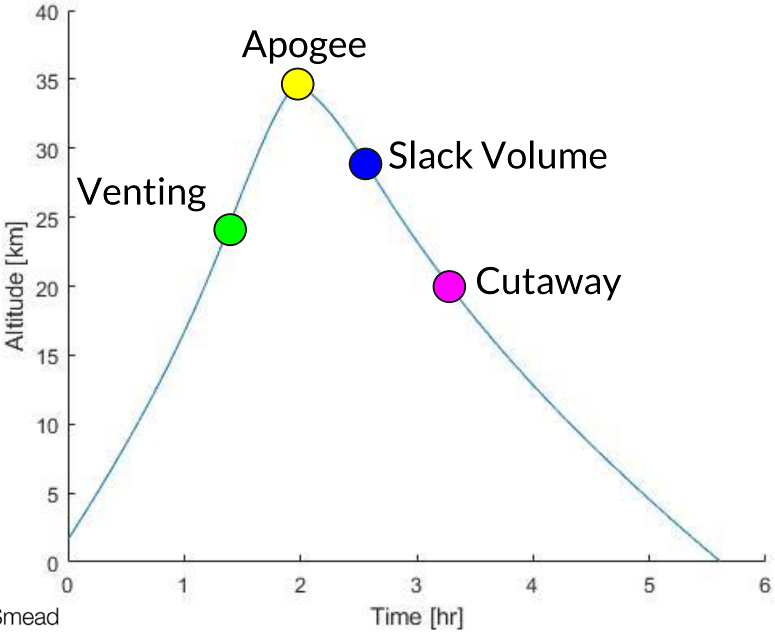
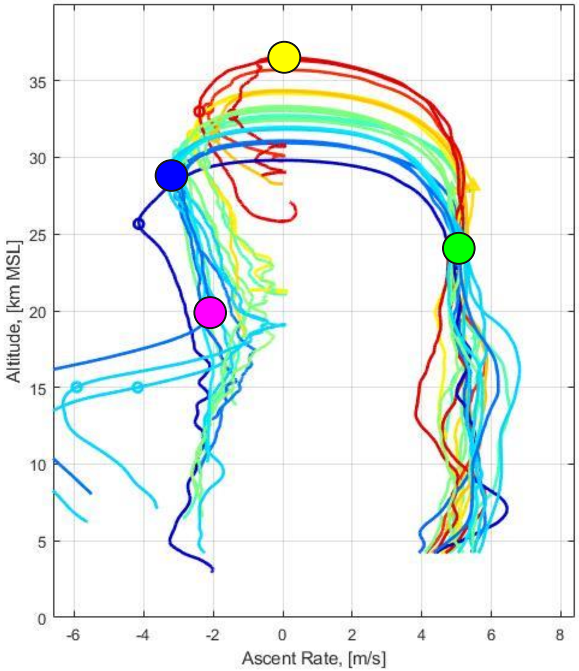
4.1. Command: Vent Helium
4.2. Command: Close Vent
4.3. Command: Cut Tether to Gondola
5. Balloon and ODDITY drift out of air traffic
6. New ODDITY assembled for next flight

Balloon Dynamics





Functional Requirements:

1.0: The descent control system shall achieve descent rates between 2 m/s and 10 m/s from the target altitude until the gondola is cut away.

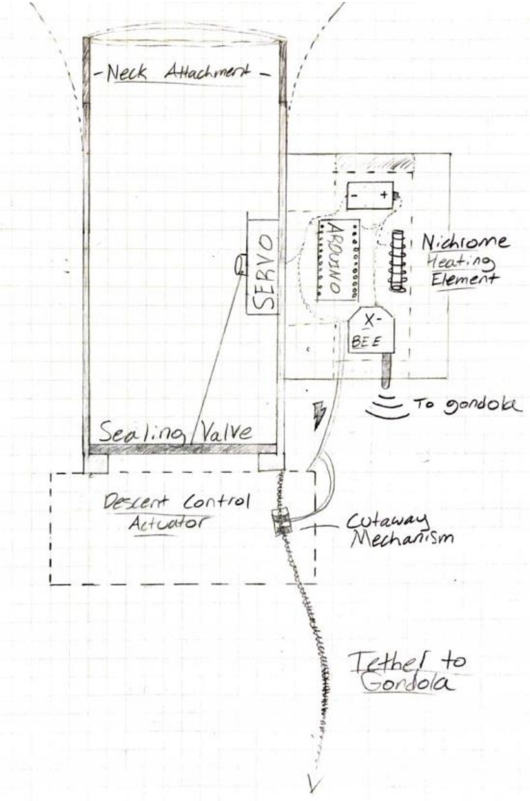
2.0: ODDITY shall survive until the gondola is cut away from the balloon.

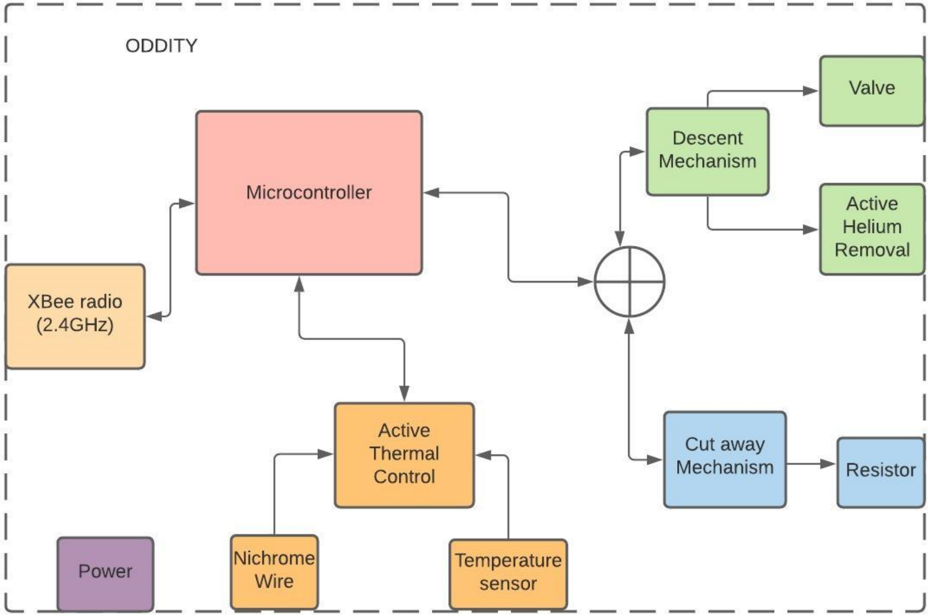
3.0: The RF communications and controls system shall have a communication link with the gondola.

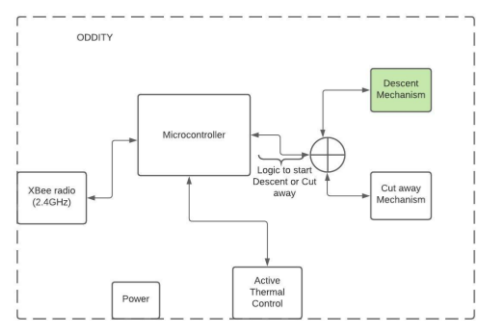
4.0: ODDITY shall not significantly interfere with the data gathering equipment.

5.0: The neck attachment system shall mount to the neck of the provided weather balloon.

ODDITY Functional Block Diagram



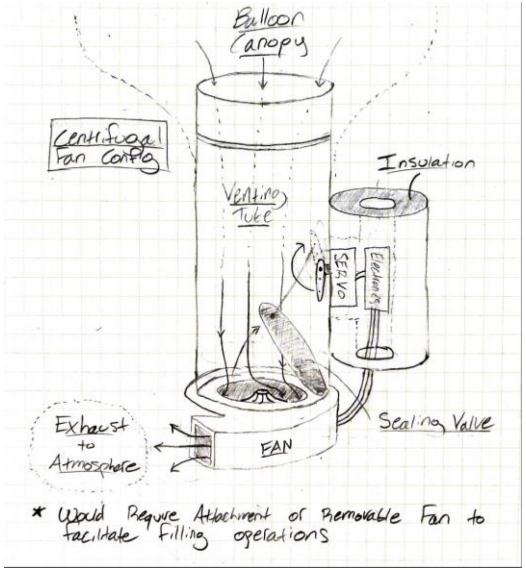




CPE 1.0: Descent Control

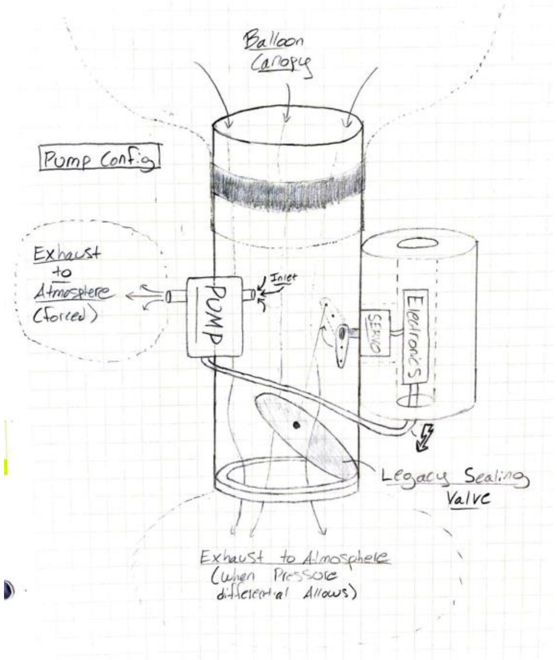
Descent Control: Fan

- Fan Performance at altitude
  - Fans are, ideally, “constant volume” devices
    - Volumetric flow rate independent of working fluid density
  - Should this hold for our applications, the volumetric flow rate provided will be more than enough to vent the additional helium required during descent.
- Fan Feasibility
  - Current Draw: ~ 680mA
  - Mass: ~ 85g
  - Rated Minimum Operational Temperature: -40°C
  - Rated flow rate at STP: 400+ LPM



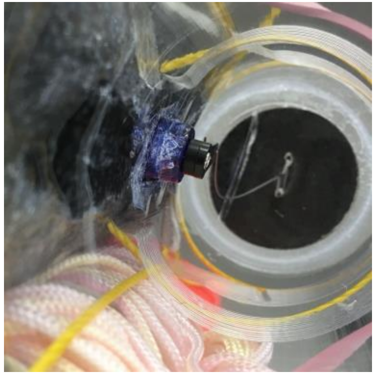
Descent Control: Pump

- Pump performance at altitude
    - Positive displacement
        - Constant volumetric flow rate no matter the atmospheric density
- Pump Feasibility
    - Current Draw: ~ 330mA
    - Mass: ~ 80g
    - Rated Minimum Operational Temperature: 5^{o}C
    - Rated Volumetric Flow Rate: 5.7 LPM

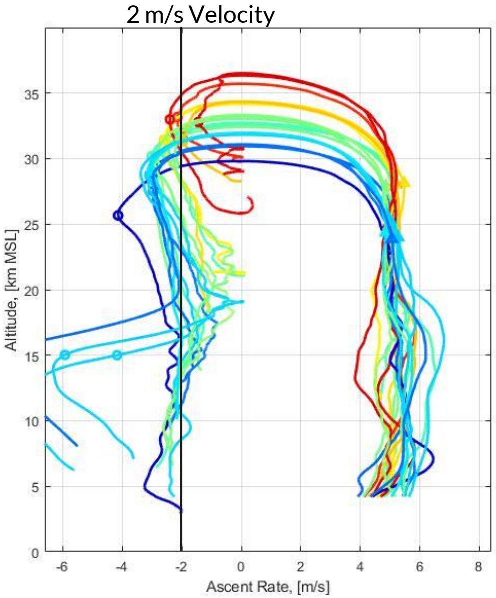


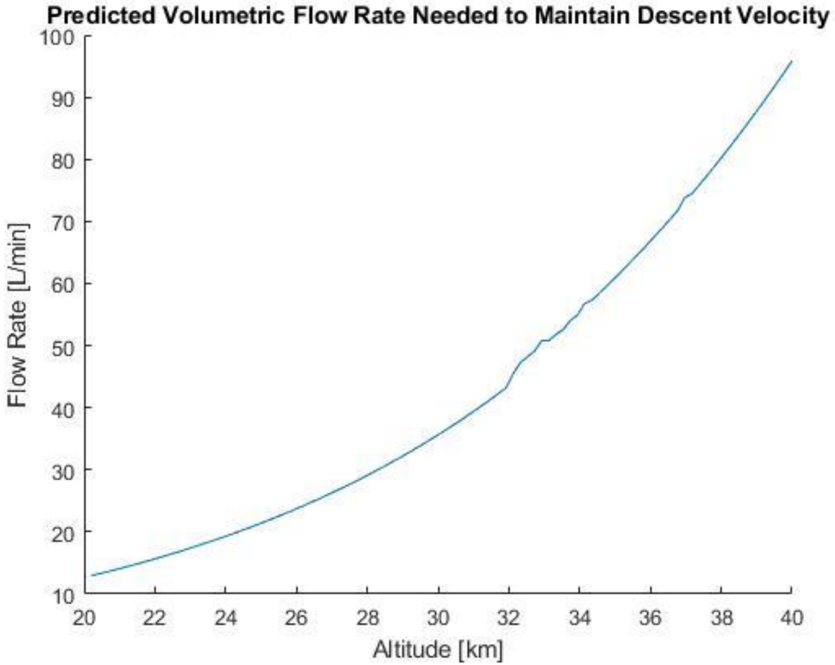
Descent Control: Active Valve

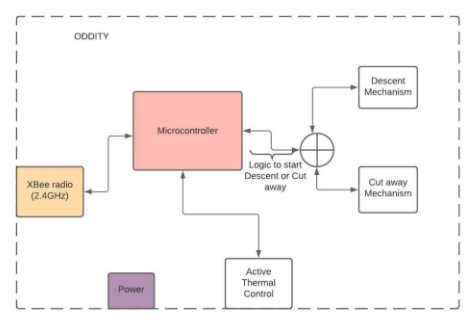
- Servo Actuated Valve
  - Foam valve with petroleum jelly acts as seal against plastic shoulder in the neck attachment tube
  - Servo forces valve into seat using thin pushrod
  - Allows for helium to be vented due to elastic energy stored in the balloon envelope
  - Will aid the fan/pump with helium expulsion
  - Simple solution to evacuate large volumes of helium
    - Low current draw and system weight
  - Fails to expel helium once no pressure differential is present



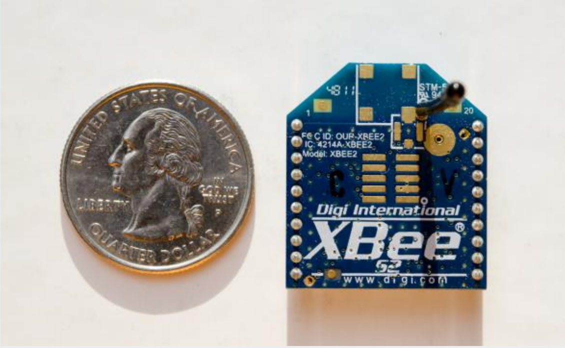
Predicting Volumetric Flow For Constant Descent

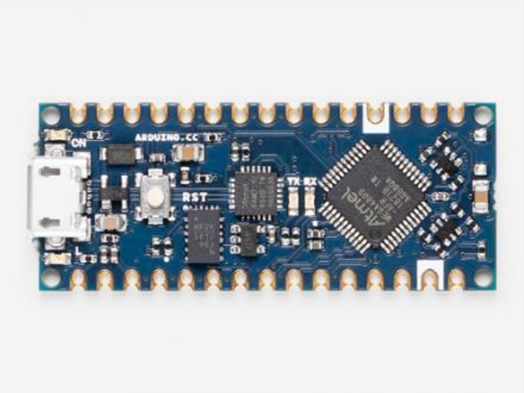






CPE 2.0: Comms, Power and Control

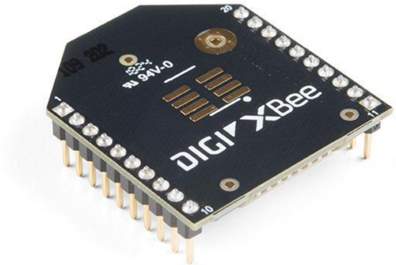




Baseline Design: Comms, Power and Control

Communications:

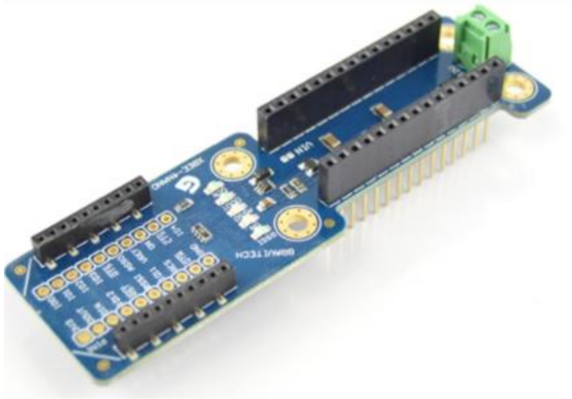
- **Digi XBee 3 Module:**
    - Frequency: 2.4 GHz
    - Line of sight range: 1.2 km
    - Transmit Power: +8dBm
    - Receiver Sensitivity: -103 dBm
    - Will be used onboard ODDITY & gondola
- **Digi XBee Pro SX Module:**
    - Frequency: 902- 928 MHz
    - Line of sight range: 105 km
    - Transmit Power: +30dBm
    - Receiver Sensitivity: -103 dBm
    - Will be used onboard gondola & on ground



Baseline Design: Comms, Power and Control

XBee and Microcontroller Connection:

- PCB
    - Design our own
- Physical Wire Connection
- Arduino Nano to Xbee Board



Baseline Design: Comms, Power and Control

Control:

- **Arduino Nano Every:**
    - Power Required: 7-12V
    - Mass: 5g
    - Size: 0.7” x 1.8”
    - Operational Temperature Range: -40°C to 125°C
    - 20 Pins
        - 20 Digital
        - 8 Analog (Can be Digital or Analog)
        - Tx and Rx pins used for Xbee

Feasibility: Comms, Power and Control

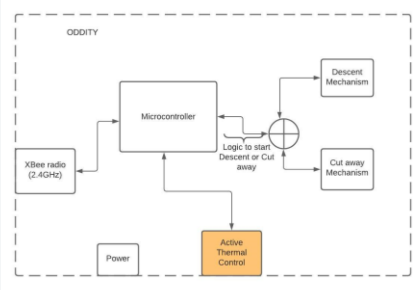
- Batteries
  - Lithium vs Alkaline => thermal consideration
  - Seperate sources to power different subsystems

Component	Voltage [V]	Current [A]	Time ON [Hr]	Battery Cap [Ah]
Arduino Nano Every	12	0.02	6	0.12
Fan/Pump	12	1	0.69	0.69
Wire Cutter	6	2	0.08	0.16
Active Thermal	6	0.22	6	1.32
Xbee 3	3.3	0.14	6	0.84

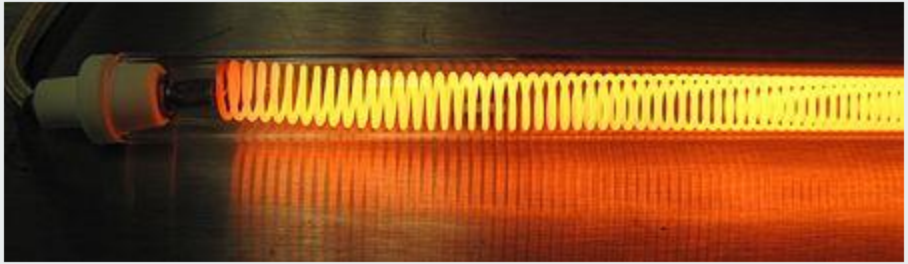
Feasibility: Comms, Power and Control

Power:

- **Boost/Buck Converters**
  - Boost or lower power source if nominal voltage too low or high respectively
  - Need depends on power requirements of individual components
- **Connectors**
  - Power source dependent:
    - JST for lithium batteries
    - Solder wires for button top batteries



CPE 3.0: Insulation and Heating



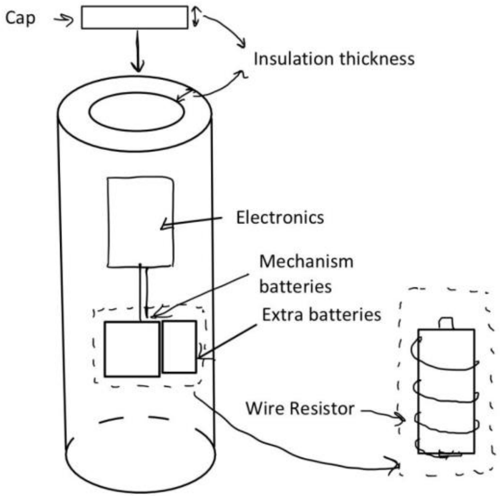
Baseline Design: Insulation and Heating

Insulation:

- Polyisocyanurate Insulation
  - Density: 33.64 kg/m^3
  - Thermal Conductivity: 0.012 W/(m*K)

Heating:

- Nichrome Wire
  - Specific Heat: 0.46 kJ/(kg*K)
  - Resistivity: 1.09 Ohm mm^2/m



Feasibility: Insulation and Heating

Temperature Requirements:

- Digi Xbee 3 module
  - -40°C to 85°C
- Arduino Nano Every
  - -40°C to 125°C
- Legacy Battery Temperature Range
  - -20°C to 60°C

$$\dot{Q}_{heater} = \dot{Q}_{loss} - \dot{Q}_{electric}$$

Estimate of Heater Power to maintain 20°C : 1.31 W

CPE 4.0: Neck Attachment

Baseline Design: Neck Attachment

Separate neck attachments will be made for each balloon made out of CAB (cellulose acetate butyrate) plastic tubes

Hwoyee balloon - 9cm neck

- Outer Diameter 9.5 cm
- Wall thickness 0.3 cm
- Cost: ~ $6
- Mass: ~ 84 g

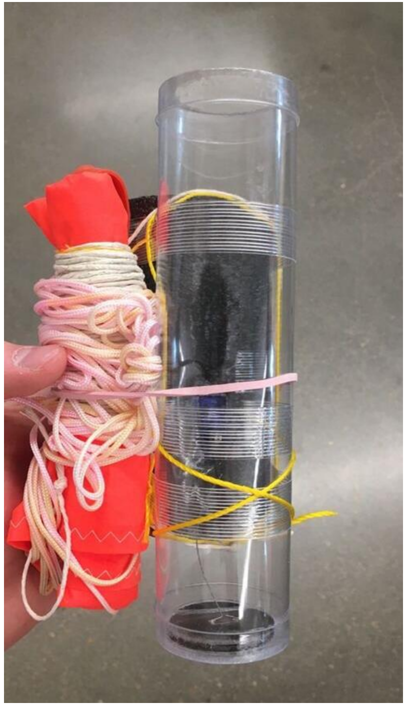
Kaymont balloon - 5 cm neck

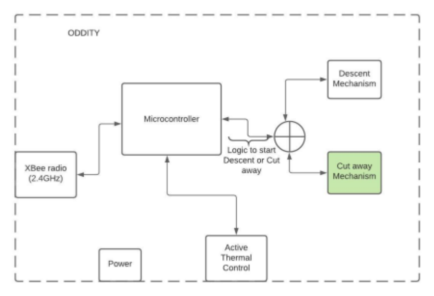
- Outer Diameter 5.1 cm
- Wall thickness 0.3 cm
- Cost: ~ $3
- Mass: ~ 35 g

Feasibility: Neck Attachment

Separate neck attachments

- Easier to attach
- Light weight
- Proven in flights



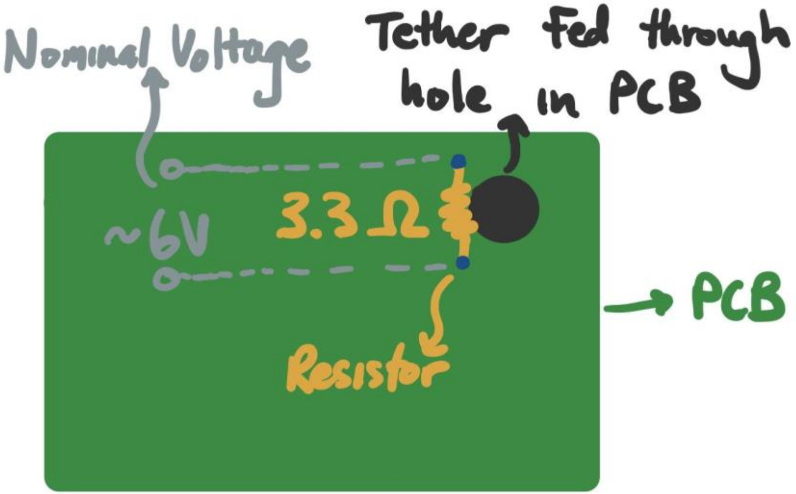


CPE 5.0: Cutaway Mechanism

Baseline Design: Cutaway Mechanism

Legacy Hot-Wire system will be utilized for the cutaway mechanism

- Consists of one ¼W metal film resistor of 3.3 Ohms
- Intended for a nominal 6V battery
- Will be turned on and off by the microcontroller
- Legacy system has been successful for over 10 flights



Summary and Future of ODDITY:

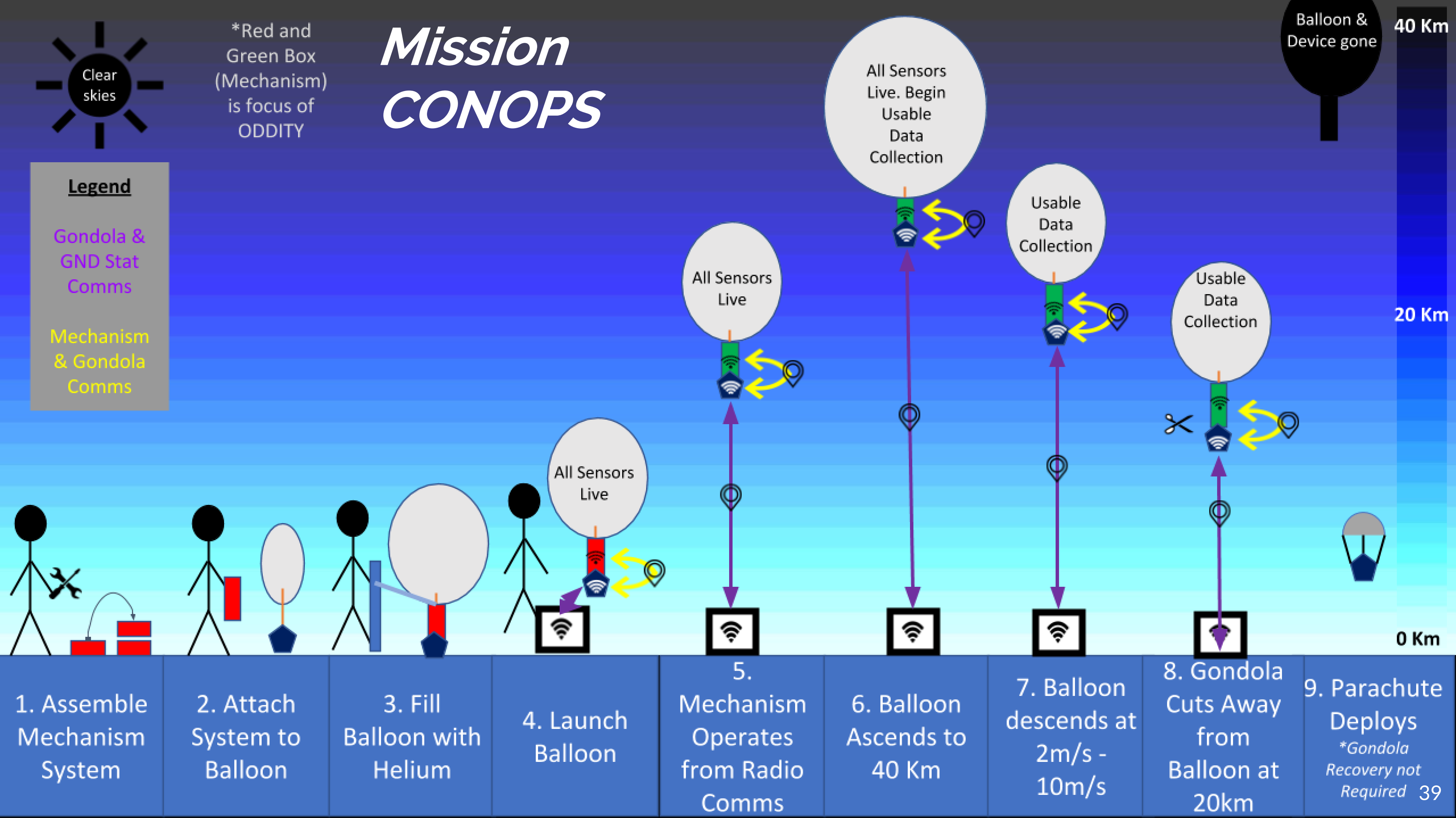
- Chosen Designs:
  - XBee radio and microcontroller have been chosen
  - Thermal control of the electronics will be taken care of by insulation and a nichrome wire resistor
  - Neck attachment method to account for both the 5cm and 9cm balloons
  - Hotwire cutaway mechanism
- Places Where More Research and Testing is Needed:
  - Battery Trade Studies
    - Type of battery / how many
    - Circuit design
  - Electronic survivability at altitude
  - Descent Control System; fan vs. pump
  - More accurate flow rates and varying descent velocities
  - Evaluate Assumptions

Questions?

Resources

Dr. Brian Argrow
Chris Roseman
Dr. Dale Lawrence
Dr. Dennis Akos
https://www.grc.nasa.gov/WWW/K-12/airplane/atmosmet.html
https://www.engineeringtoolbox.com/standard-atmosphere-d_604.html
https://www.sparkfun.com/products/13855
https://www.batteryjunction.com/duraacell-cr123a.html
https://www.batterymart.com/p-a28px-6v-alkaline-photo-battery.html
https://www.acmeplastics.com/acrylic-tubes/clear-extruded-acrylic-tube
https://www.petropackaging.com/plastic-tubes/clear-stock-butyrate-tubes/
https://www.usplastic.com/catalog/item.aspx?itemid=33338&clickid=related-slider
https://store.arduino.cc/usa/nano-every
https://www.boxerpumps.com/en/products/miniature-diaphragm-pumps-air-gas/
https://www.digikey.com/en/products/detail/delta-electronics/BFB0712HHD77/8680960

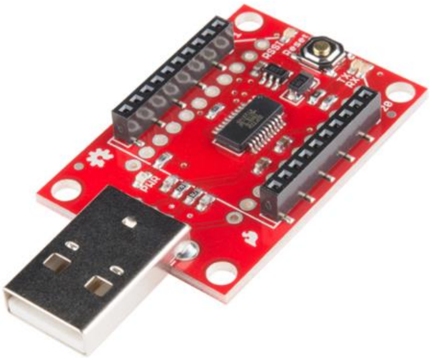
Appendix:


Mission CONOPS
Clear skies
*Red and Green Box (Mechanism) is focus of ODDITY
Legend
Gondola & GND Stat Comms
Mechanism & Gondola Comms
Balloon & Device gone
40 Km
20 Km
0 Km
All Sensors Live
All Sensors Live
All Sensors Live. Begin Usable Data Collection
Usable Data Collection
Usable Data Collection
1. Assemble Mechanism System
2. Attach System to Balloon
3. Fill Balloon with Helium
4. Launch Balloon
5. Mechanism Operates from Radio Comms
6. Balloon Ascends to 40 Km
7. Balloon descends at 2m/s - 10m/s
8. Gondola Cuts Away from Balloon at 20km
9. Parachute Deploys
*Gondola Recovery not Required

Baseline Design: XBee Programming

XBee Programming:

- SparkFun XBee Explorer Dongle
  - FT231X USB-to-UART converter
  - XCTU software



Feasibility: Batteries

Component	Nominal Volts [V]	Nominal Current Draw [A]	Time ON [hr]	Power [W]	Wh	Needed Battery Capacity [Ah]		Notes	
Arduino Nano Every	12.00	0.02	6.00	0.24	1.44	0.12		Volt: 7 - 12V	
Xbee 3	3.30	0.14	6.00	0.45	2.67	0.81		Volt: 2.1 - 3.6V	
Wire Cutter	6.00	2.00	0.08	12.00	1.00	0.17		Confirm Time ON: 5 min?	
Fan/Pump	12.00	1.00	0.69	12.00	8.33	0.69		Confirm Current and Time On	
Active Thermal	6.00	0.22	6.00	1.31	7.86	1.31		Assume 6V?	
	What will be powered with Nano?								

Model for Heater Power Required

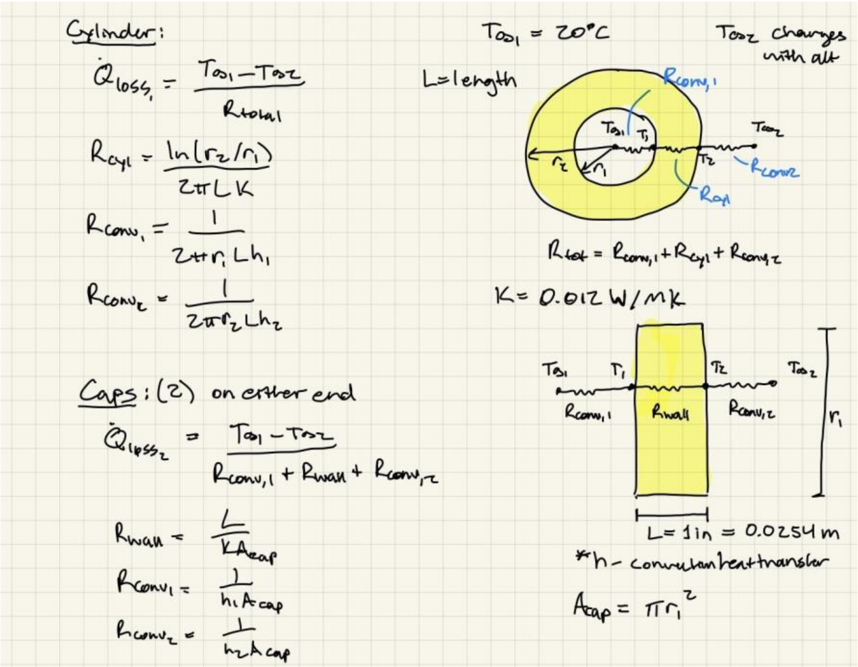
Heat Balance Equation:

$$\dot{Q}_{heater} = \dot{Q}_{loss} - \dot{Q}_{electric}$$

Heat generated by electronics:

$$\dot{Q}_{electric} = P = IV$$

Mathematical model of the atmospheric temperature at altitude was referenced from NASA



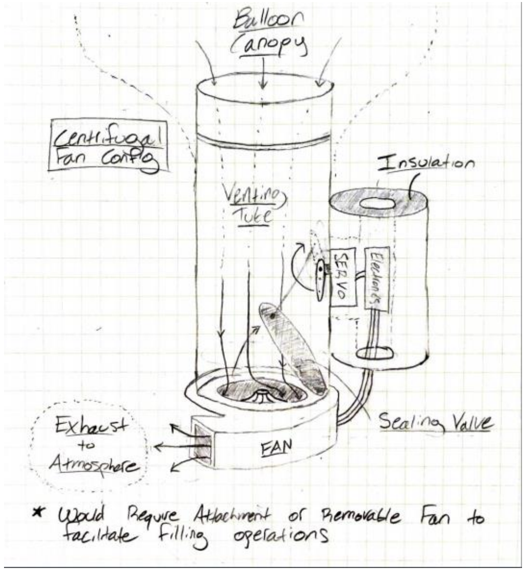
Model for Heater Power Required

Assumptions:

- Steady 1-D heat transfer for each temperature
- Constant material properties
- Radiation heat transfer was not considered
- Air and surfaces have uniform temperature

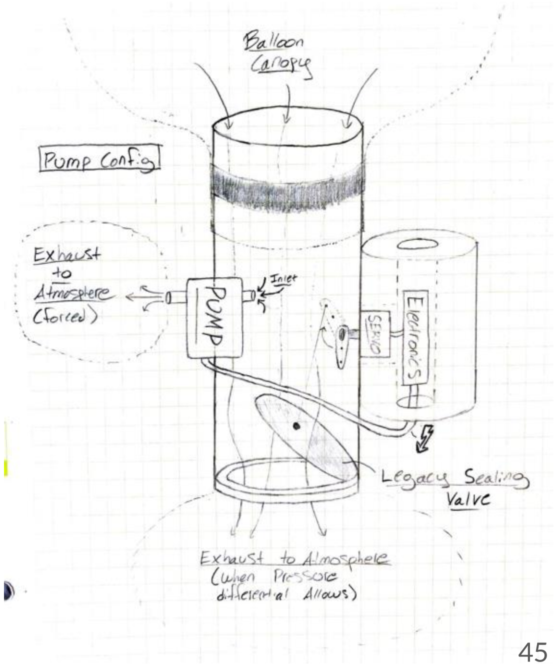
Buoyancy Control: Fan System as a Whole

- Legacy valve system is mounted inside the neck attachment tube to facilitate low current draw and high flow rate helium expulsion
- Fan mounts beneath the valve on the neck attachment tube to allow it to evacuate helium and allowing the valve to seal against the fan housing
- Tube is attached to fan exhaust and valve is opened in order to fill balloon with helium
  - Fan will free-wheel as helium is pumped in, providing little resistance to the flow



Buoyancy Control: Pump System as a Whole

- Legacy valve system is mounted inside the neck attachment tube to facilitate low current draw and high flow rate helium expulsion
- The pump mounts to the side of the neck attachment tube with a pass through to allow helium to be removed from the balloon.
- Current helium filling methods are able to be used to fill the balloon prior to flight
    - Helium filler fits over lower portion of neck attachment tube and the valve is opened



How the Balloon will be Filled with Helium

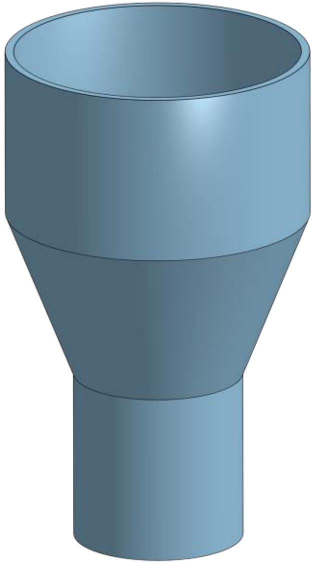
1. Helium filler is stretched over exhaust end of neck attachment tube
2. Legacy hardware valve is opened to allow helium into the balloon
3. Helium flows into balloon, bypassing the fan/pump
4. Buoyant force is measured against control weight
5. Legacy hardware valve is closed to trap helium inside the balloon
6. Helium filler is removed from neck attachment tube

Baseline Design: Funnel Neck Attachment

Kaymont balloon 5cm neck only uses the neck attachment

Hwoyee balloon 9cm neck uses the funnel and the neck attachment

- Approximately 100g
- Hwoyee Balloon does not provide more mass allotment



FAA Regulations:

FAA Part 101:

- First 1,000ft of altitude cannot be above any people who are not associated with the operation
- Cannot be used in a manner that creates a hazard to people and property not associated with the operation
- Equipped with two methods to terminate the flight of the balloon (cut away and buoyancy control)
- Notify FAA 6-24hrs prior to flight
- Gondola tether must require no more than 50lbs to break at any point unless it has colored pennants or streamers attached

What is HYFLITS?

- HYFLITS (Hypersonic Flight In the Turbulent Stratosphere) research team is dedicated to answering complex questions in regards to future hypersonic and how they interact with middle stratosphere turbulence and air particles.
  - To take measurements of the upper atmosphere
  - Gain information to better understand the conditions at very high altitudes

What Prompted this Project?

- Background
  - HYFLITS uses weather balloons to take sounding measurements of the upper atmosphere
  - A controlled descent is required to collect accurate turbulence data
- The current design facilitates descent with a valve in the neck, which opens, and allows helium to escape
  - A more robust method for evacuating helium is desired
  - Current buoyancy control system allows for a maximum altitude of ~35 km (40 km desired)
- More minor upgrades on sub-systems are warranted to further aid the success of future missions
  - More dynamic communications
  - Adjustable neck attachments (5cm and 9cm)
  - More efficient insulation and thermal control
- This prompts designing a new system to facilitate descent

Numerical Simulations

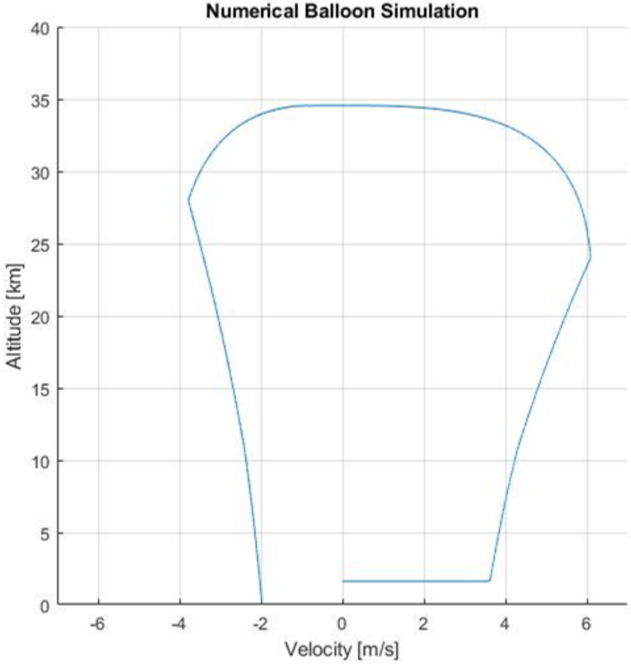
Approximated Experimental Data

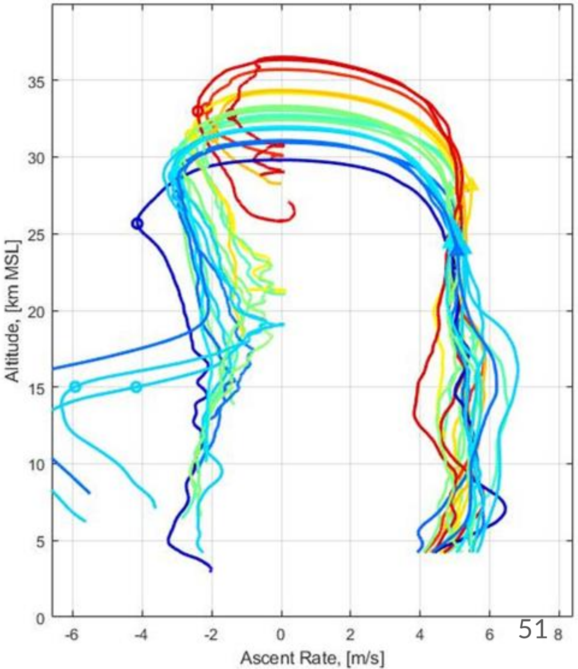
Matches Dr. Lawrence's Data

Additionally validated by hand at Key points

Utilizing Ode45

Constant mass flow venting





Apogee Determination

At Apogee, velocity and acceleration are 0 leading to the simplified form of our equation.

$F_{Buoyancy} = m*g$

Given our assumptions $P_{atm} = P_{He}$ and $T_{atm} = T_{He}$. The equation simplifies:

$m_{He} = (m_b+m_{pl})*g/(R_{He}/R_{atm} - 1)$

Ideal Gas Law to get volume and diameter

Iterate at increasing altitudes until the diameter is greater than the manufacturer's burst diameter

Simplifying Assumption

- Drag on the balloon/system/gondola is approximated as a sphere
- Pressure differential inside the Balloon is negligible: $P_{atmosphere} = P_{Balloon}$
- Wind effects horizontally and vertically are ignored
- Volume of the balloon is the only volume considered for buoyancy calculations
- Atmospheric data is from standard atmosphere charts
- All gasses are Ideal

Mass Estimation

Component:	Mass:
Fan/Pump	80g/86g
Battery:	TBD
Neck Attachment Tube:	35g (*5cm*) || 84g (*9cm*)
RF Communications & Controller:	8g
Valve System:	30g
Insulation & Heating:	10g
Cutaway Mechanism:	10g
Totals:	**173g / 179g (*5cm*) || 222g / 228g (*9cm*)**