SpaceChute

High Altitude Parachute Recovery System

"Everything looks nonsensical before it works."
- Burt Rutan

Chute Design:

Basic Forces

$$F_D = \tfrac{1}{2}\,\rho\, C_d\, A\, v^2$$

Where

$\boldsymbol{F_D}$	Drag force
ρ	Density of air = 1.22 kg/m^3
$\boldsymbol{C_d}$	Drag coefficient
$\boldsymbol{A}$	Area of the chute
$\boldsymbol{v}$	Velocity through the air (descent velocity)

$$F_G = m\, g$$

Where

$\boldsymbol{m}$	Mass of the payload
$\boldsymbol{g}$	Acceleration of gravity = 9.81 m/s^2

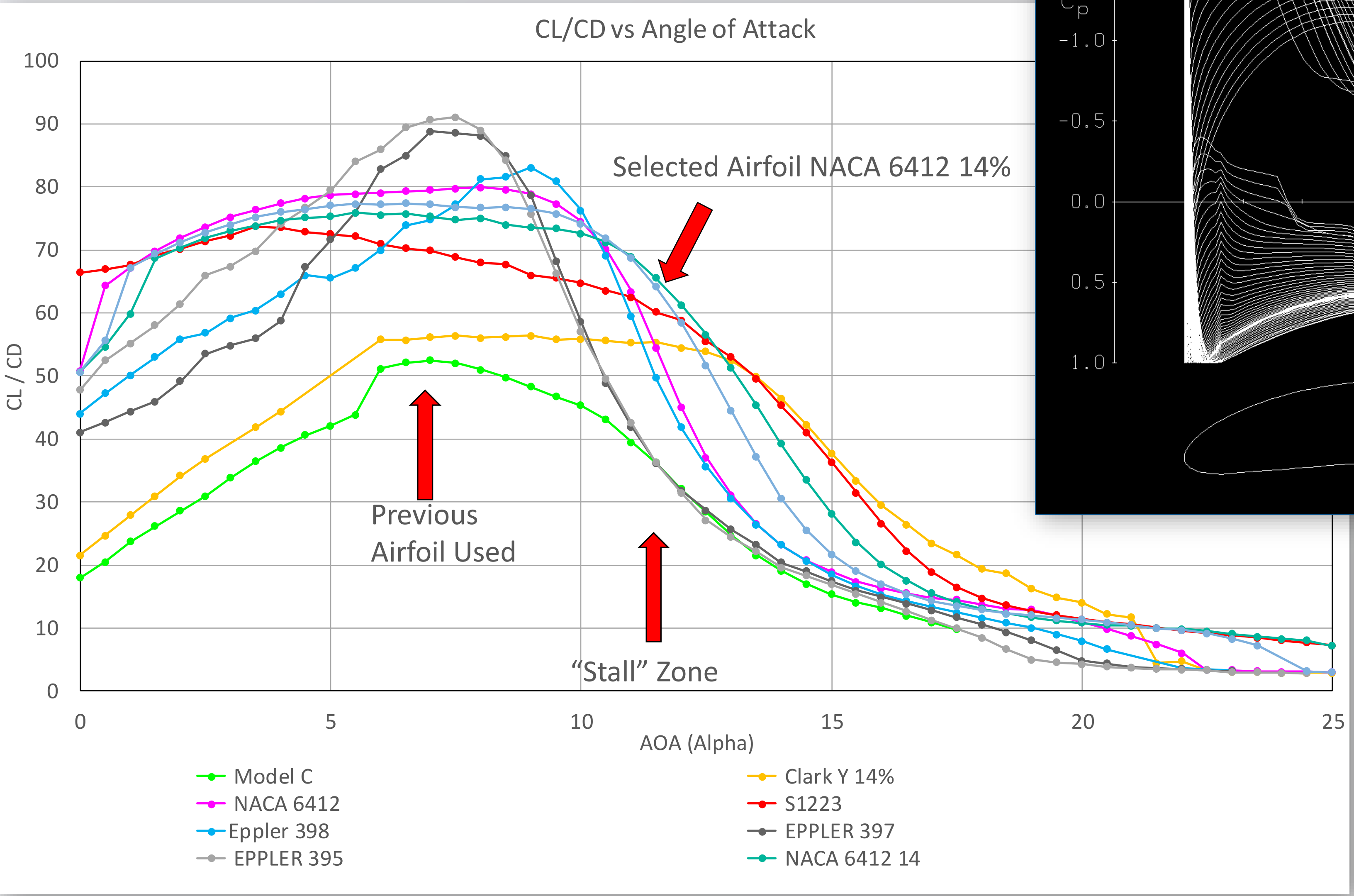
Descent Velocity:

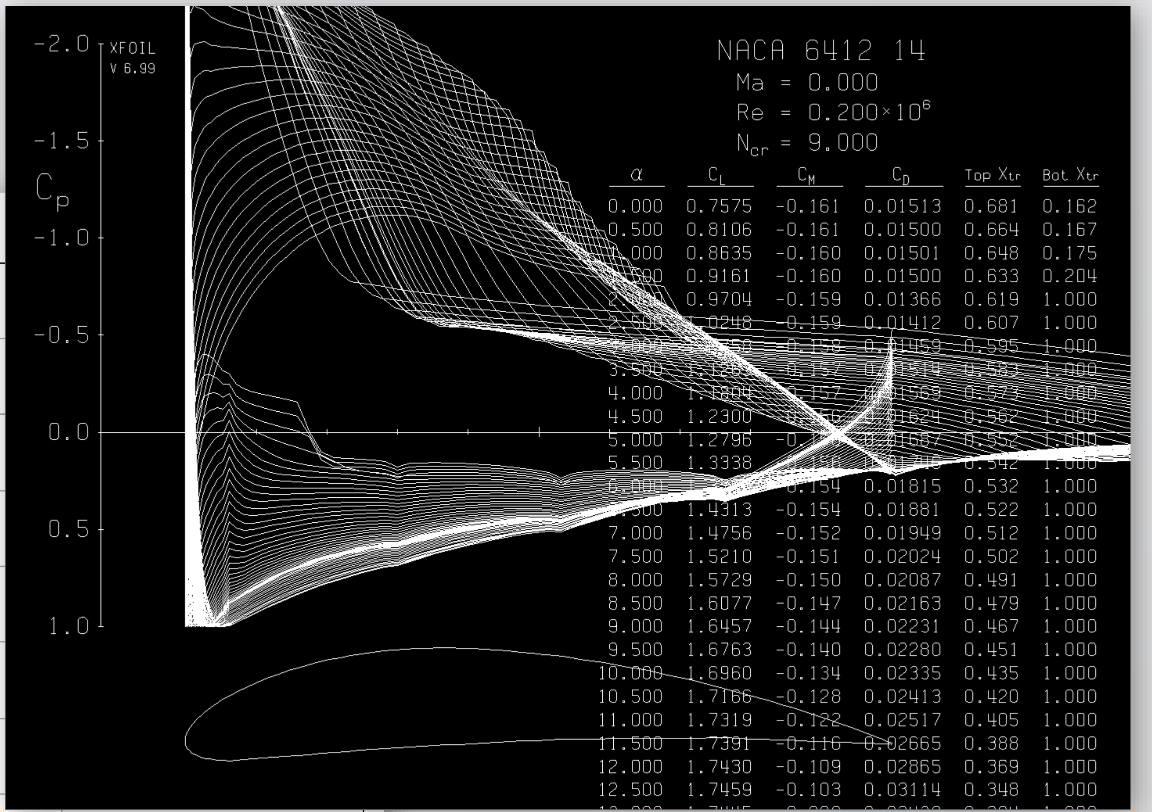
$$v = \sqrt{\frac{2\, m\, g}{\rho\, C_d\, A}}$$

depends on air density and chute area

Chute Design

Airfoil Selection



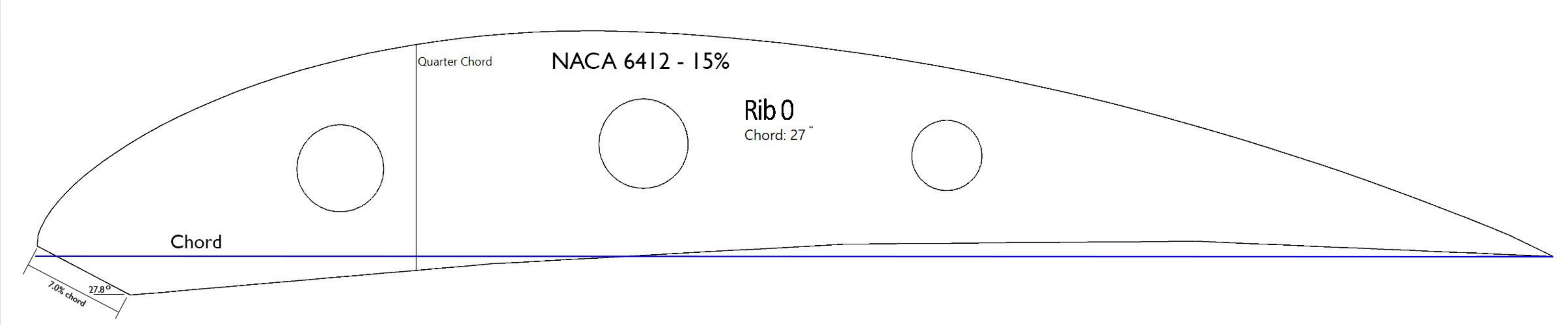


XFOIL Software

To maximize glide angle, selected highest CL/CD with reasonable stall characteristics. Selected NACA 6412 14% but later changed to NACA 6412 15%

Chute Design
Airfoil

- NACA 6412 with 15% thickness at Quarter Chord.
- Bottom of airfoil is concave so all measurements (e.g. angle of attack) are referenced from chord line.
- Inlet Cut is 7% of chord at 27.8 º.
- Each rib is scaled to chord length defined by wing shape.

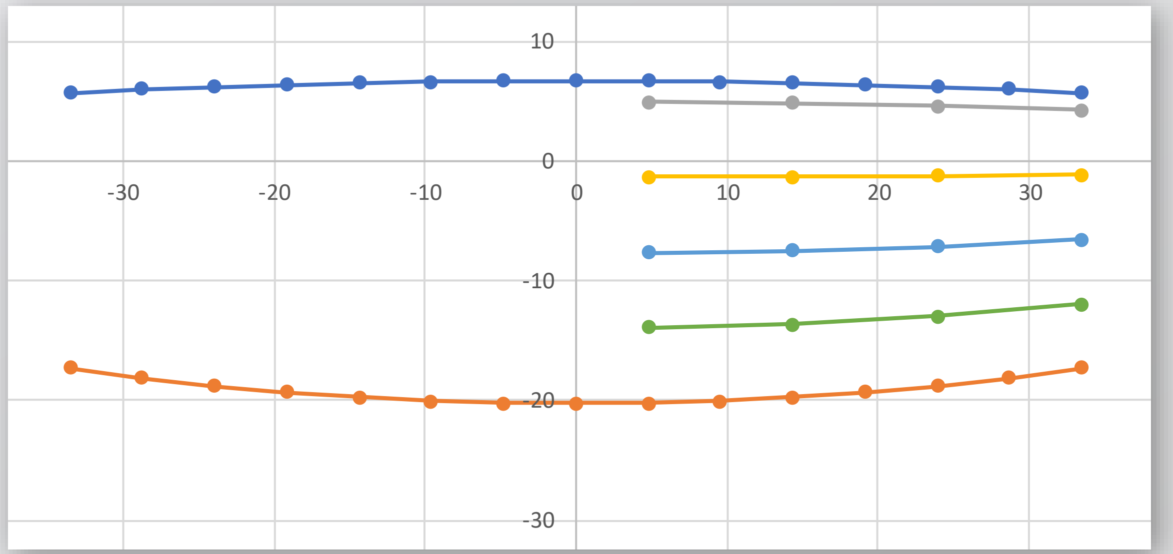


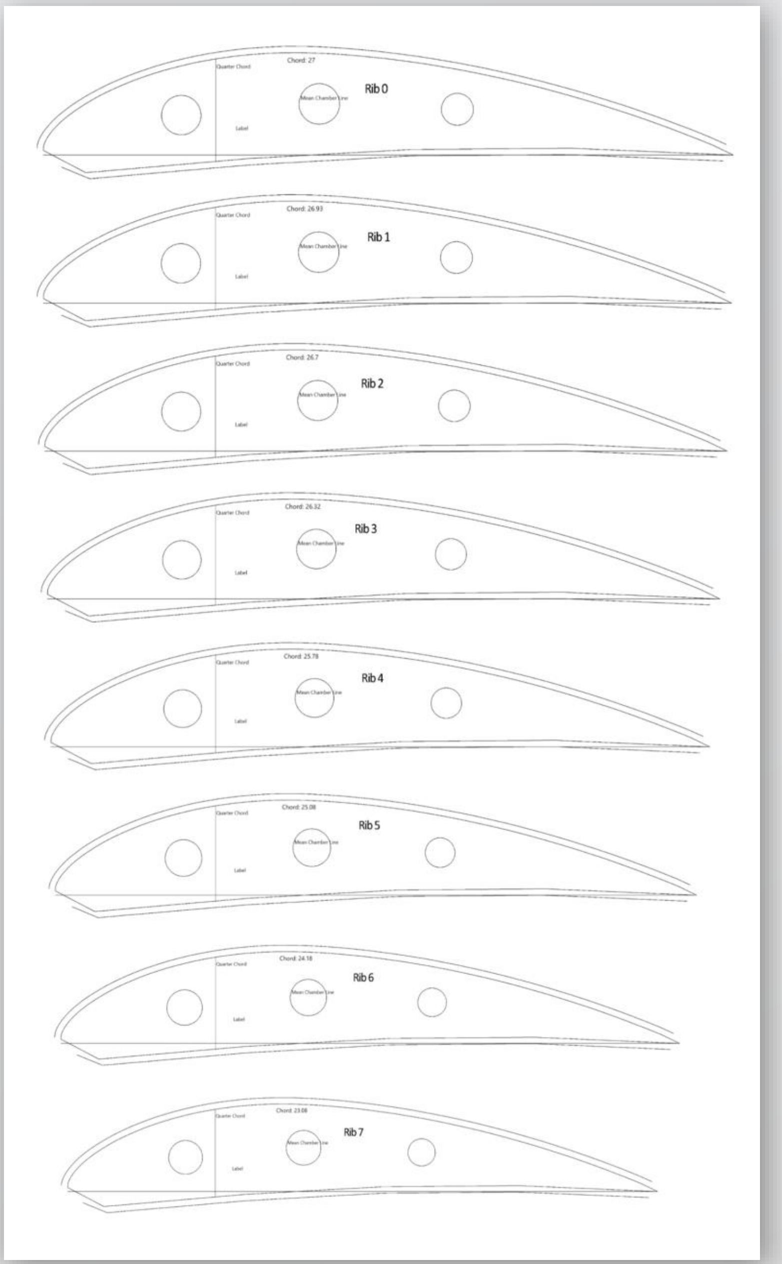
Chute Design

Basic Design Parameters

Wing shape is elliptical for increased efficiency

Payload weight	2.36 kg	
Area	1.11 m2	Determines basic descent rate
Wing Loading	2.12 kg/m2	Determines speed (higher than designed for)
Span	1.70 m	
Chord	0.69 m	
Aspect Ratio	2.61	Within range of military and sport chutes
Root:Tip Ratio	1.17	Modeled after sport chutes



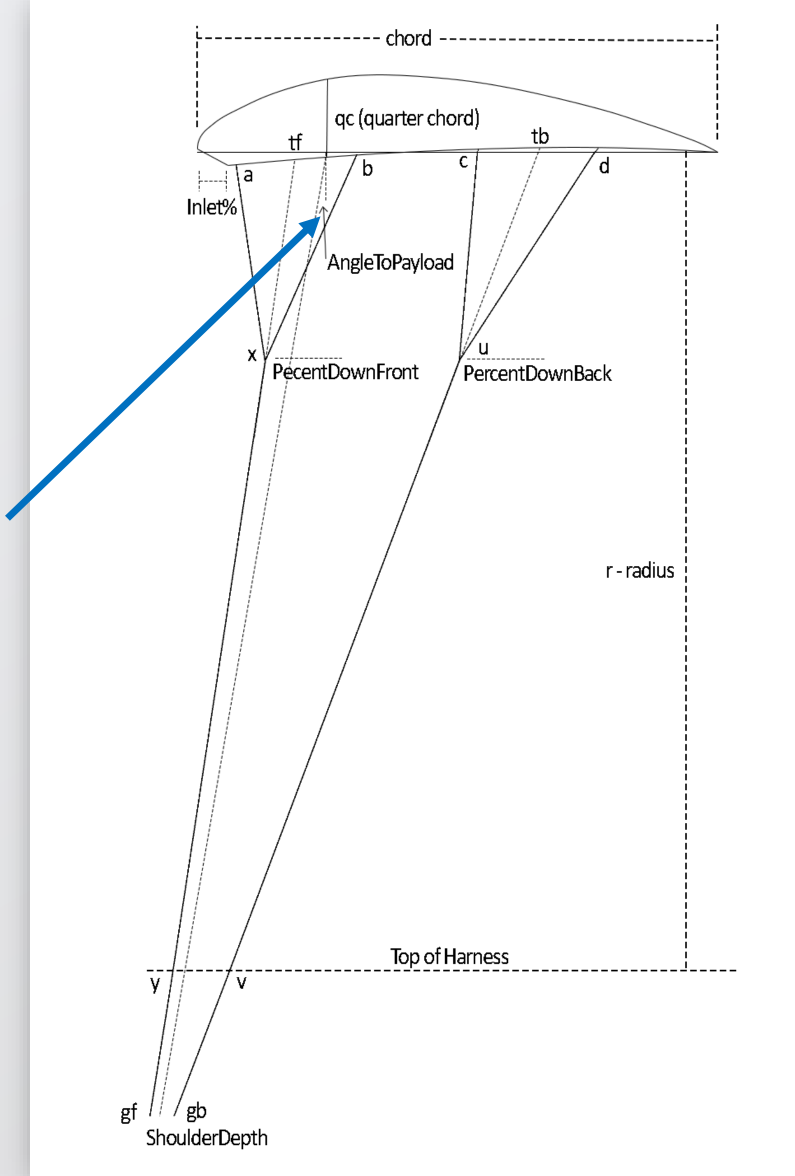


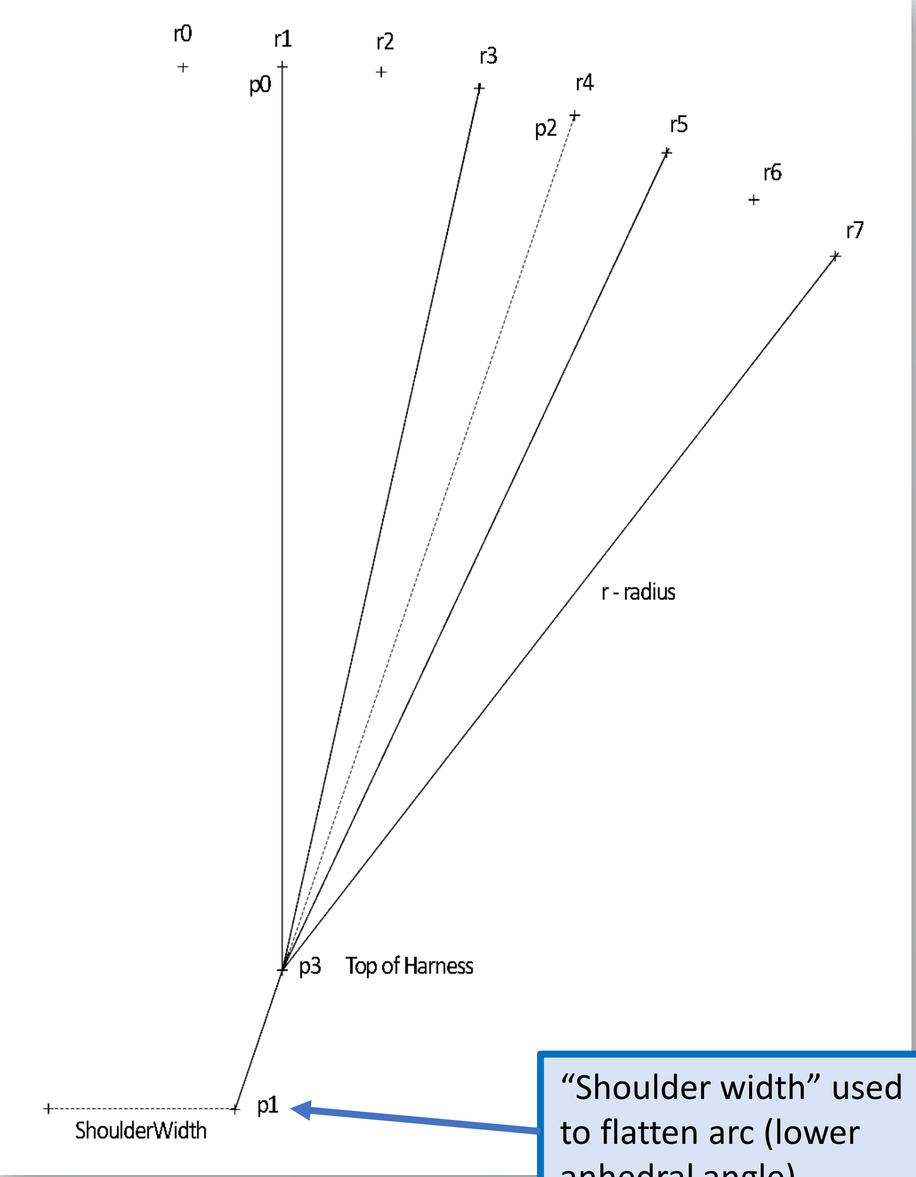
Chute Design

Calculation of Line Lengths

Line lengths are calculated using 3D model, across span and elliptical shape of cute to ensure angle of chute is uniform throughout arc.

Angle between payload and quarter chord set at 10º. This can be changed during flight. Capsule is capable of pulling front lines down while releasing rear lines the same amount to adjust pitch angle.





"Shoulder width" used to flatten arc (lower anhedral angle)

Chute Design

Testing Final Construction

Chute put in flexible frame and suspended from points identical to capsule anchor points. Frame follows contour of airfoil bottom so top of frame is parallel to chord line.

Angle from Quarter Chord to capsule checked to be at 10 degrees.

Chutes checked for level.

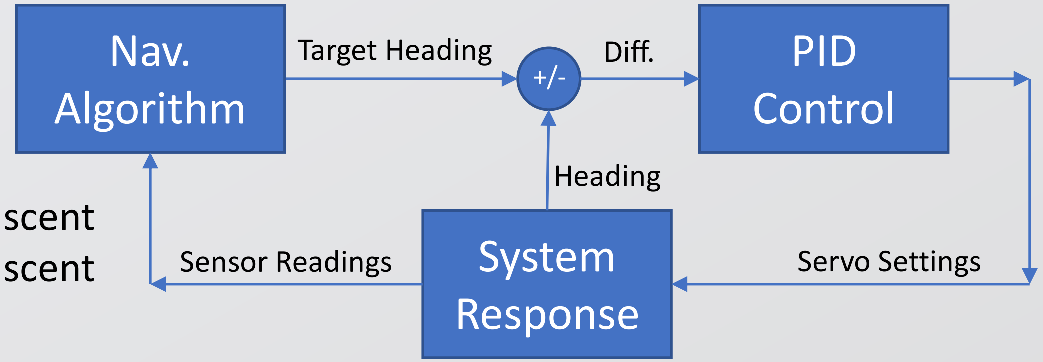
Effect of providing “shoulder width” in capsule for lowering anhedral angle can be seen in front shot.

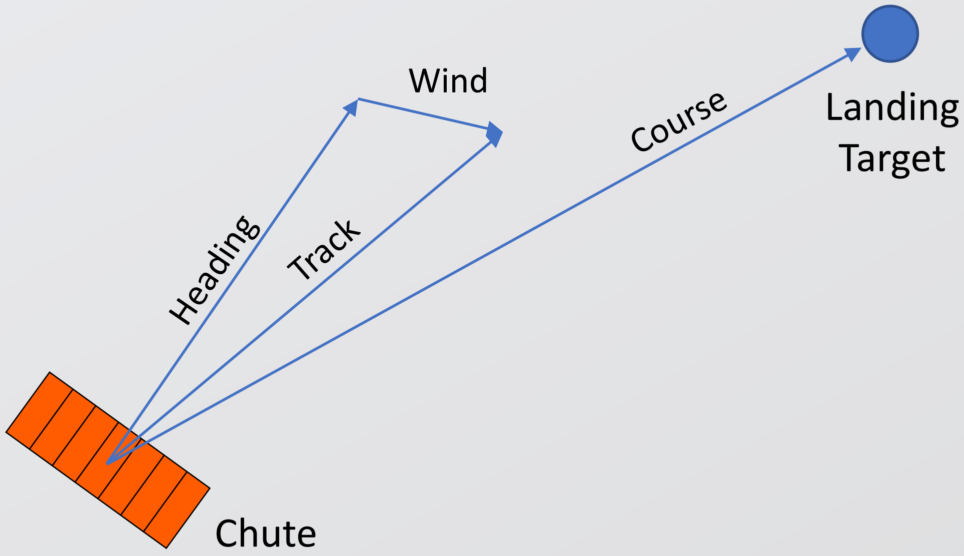
Navigation

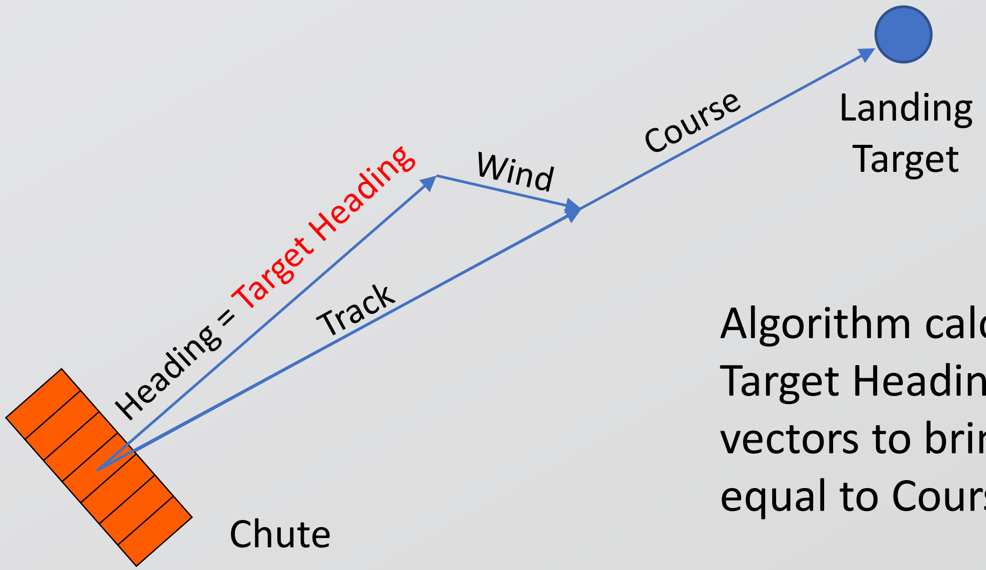
Targeting Algorithm

Vectors calculated every 20 ms. Corrective steering applied each second.

• Heading	Magnetometer
• Air Speed	Stored (assumed)
• Track	GPS
• Ground Speed	GPS
• Wind Direction	Measured during ascent
• Wind Speed	Measured during ascent
• Location	GPS
• Target Location	Stored
• Course	Calculated
• Distance to Target	Stored
• Altitude	GPS + Barometer



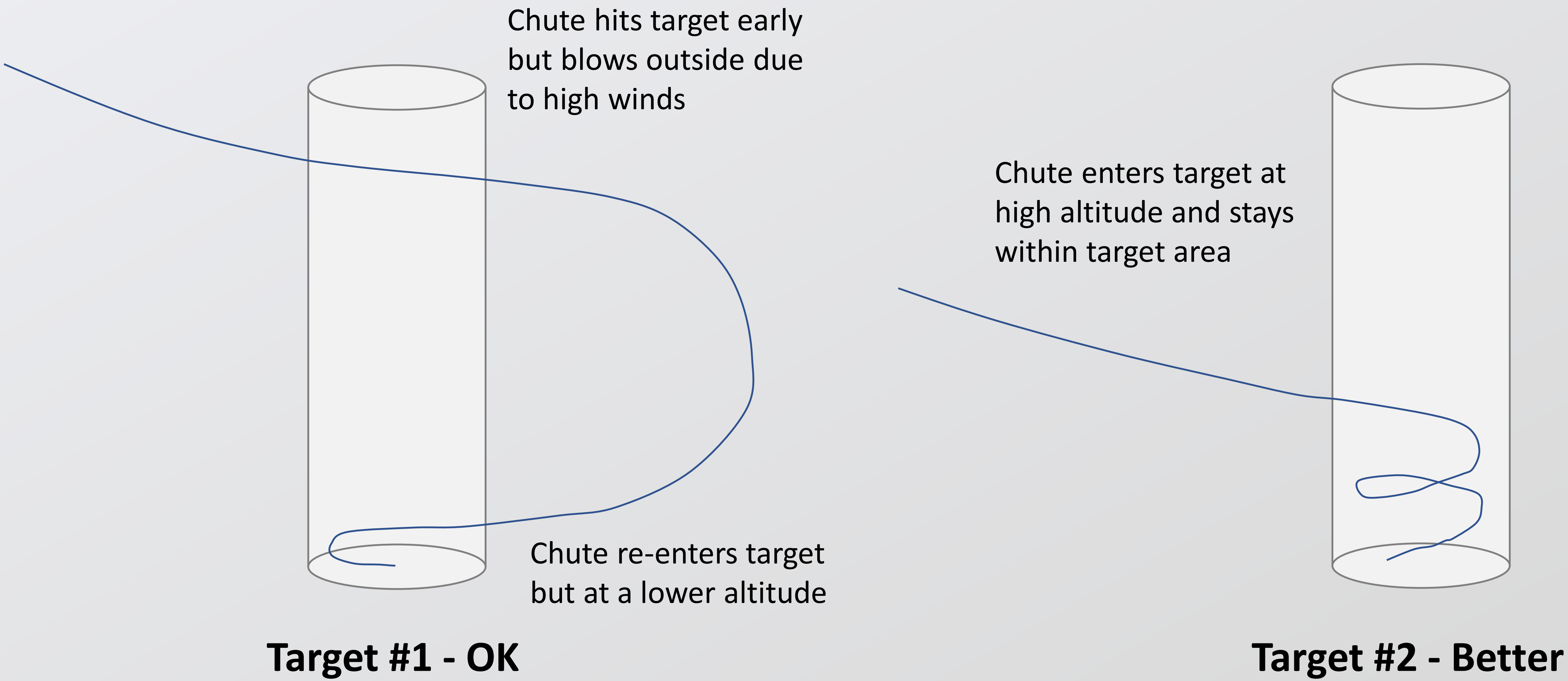




Algorithm calculates Target Heading from vectors to bring Track equal to Course

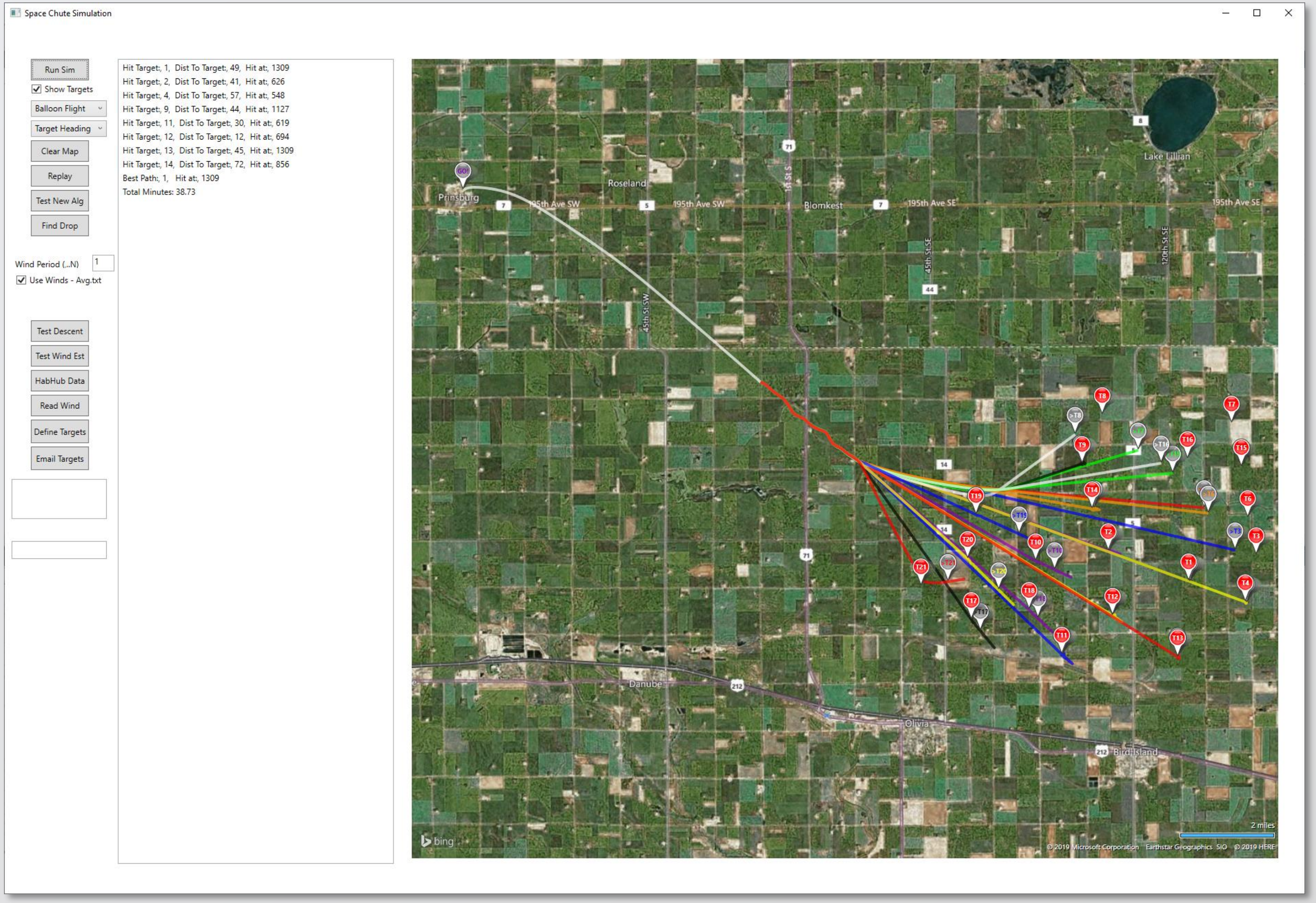
Navigation

Selecting the “Best” Target



Navigation

Simulation Software



Software simulating flight conditions is used to predict:

- where the balloon will carry the payload,
- where the payload is released,
- where the chute will travel if steered to 20 possible target landing sites.

The same software is used on-board to determine the best landing target and to steer the chute.

The winds aloft data for the time of flight is used in both the simulation and actual on-board software.

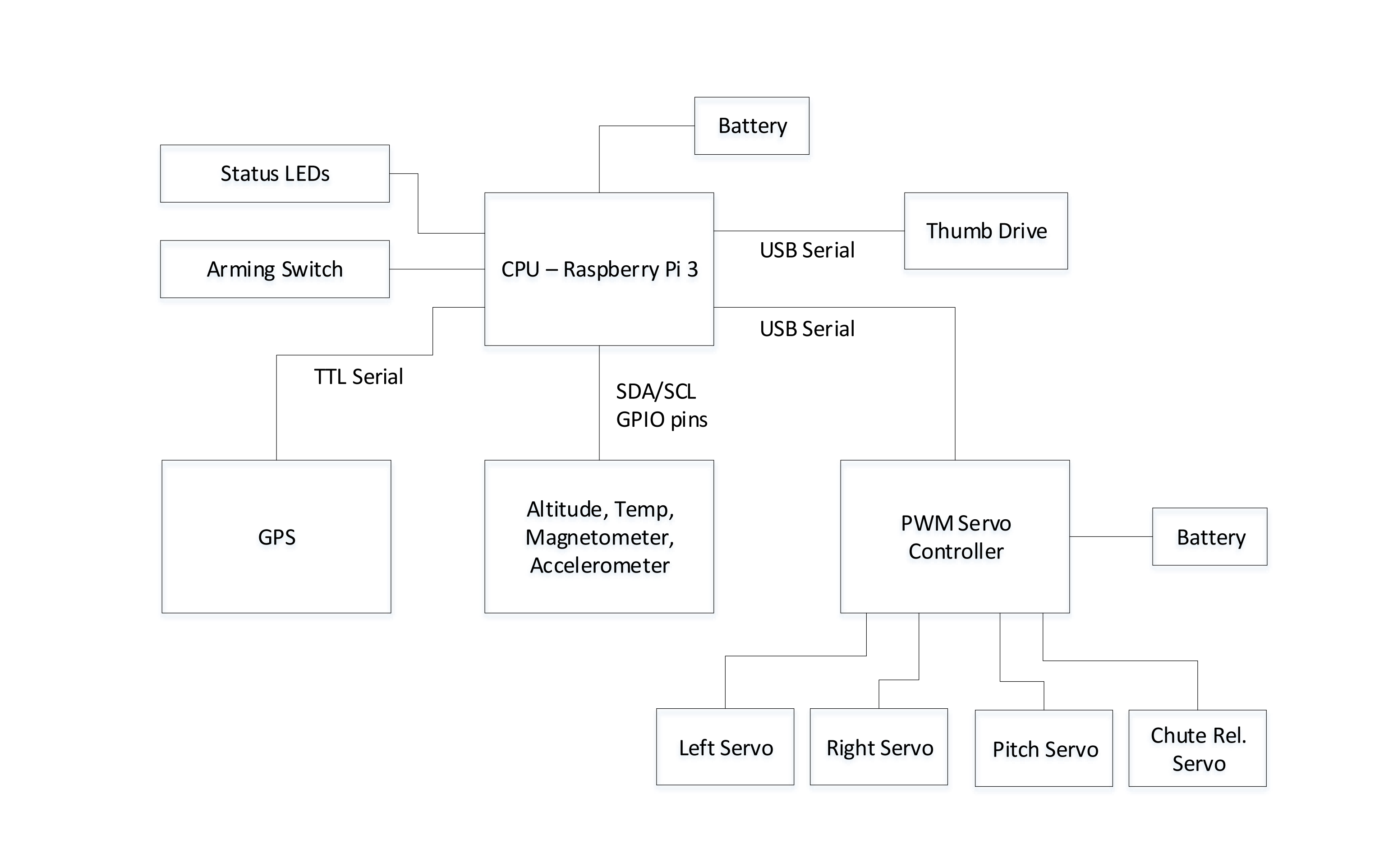
Simulation above shows balloon ascending south-east from launch site (grey), chute being released and first doing fixed maneuvers (red), chute targeting approx. 20 landing sites.

Navigation

Actual Path of Test Drop #4

- Dropped from 5,000 feet
- Flight time ~6 minutes
- Parachute turns towards and tracks target
- Once past target, chute turns around again.

Electrical Design
Schematic



Raspberry Pi 3 with Custom HAT to add off-the-shelf sensors.

LEDs used to monitor "GO – NO GO Conditions.

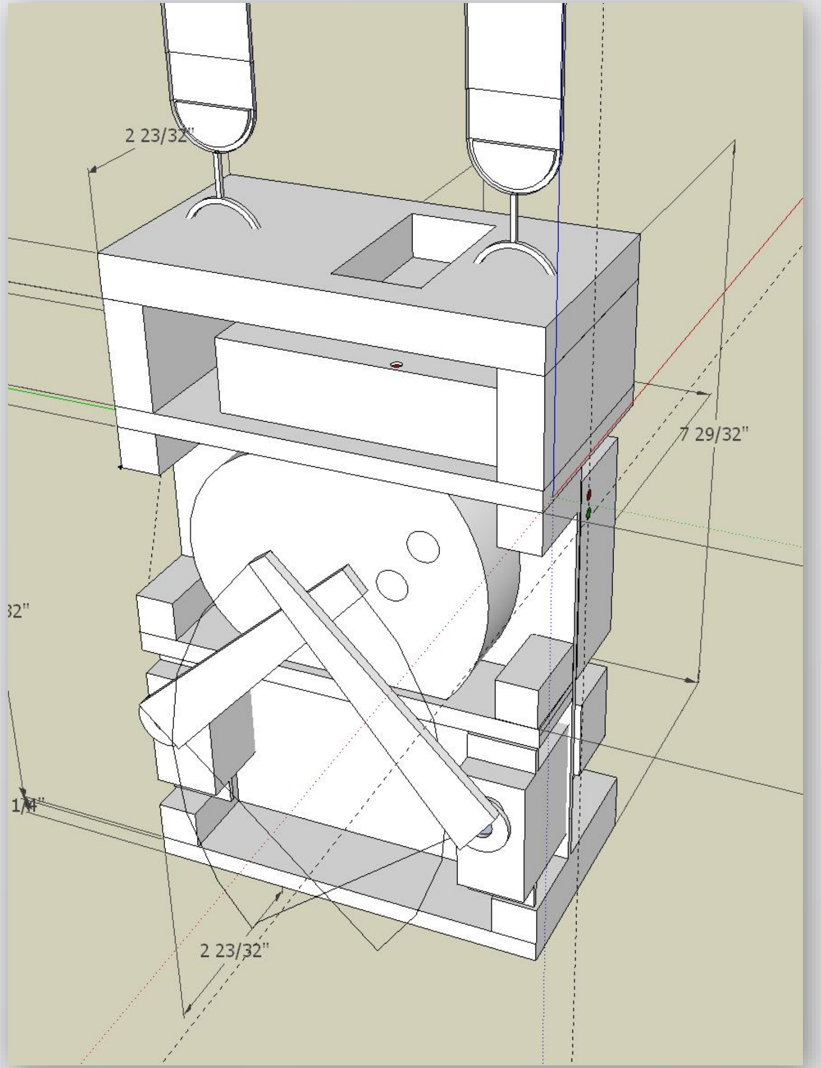
Arming button starts launch program. Puts program in ASCENT mode. Waits until altitude reaches target altitude or time expires, then deploys chute.

Capsule Design

Test Drop 1 to 4 Capsule – Designed for 5,000 ft. drop

Measured flight characteristics and ability to seek target site.

Note opposing and offset servo arms to save space.



Capsule Design

Test Drop 5 Capsule – Designed for 33,000 ft (10 km) Drop

Test ability of chute to open at 10 km.

Test ability to seek target site.

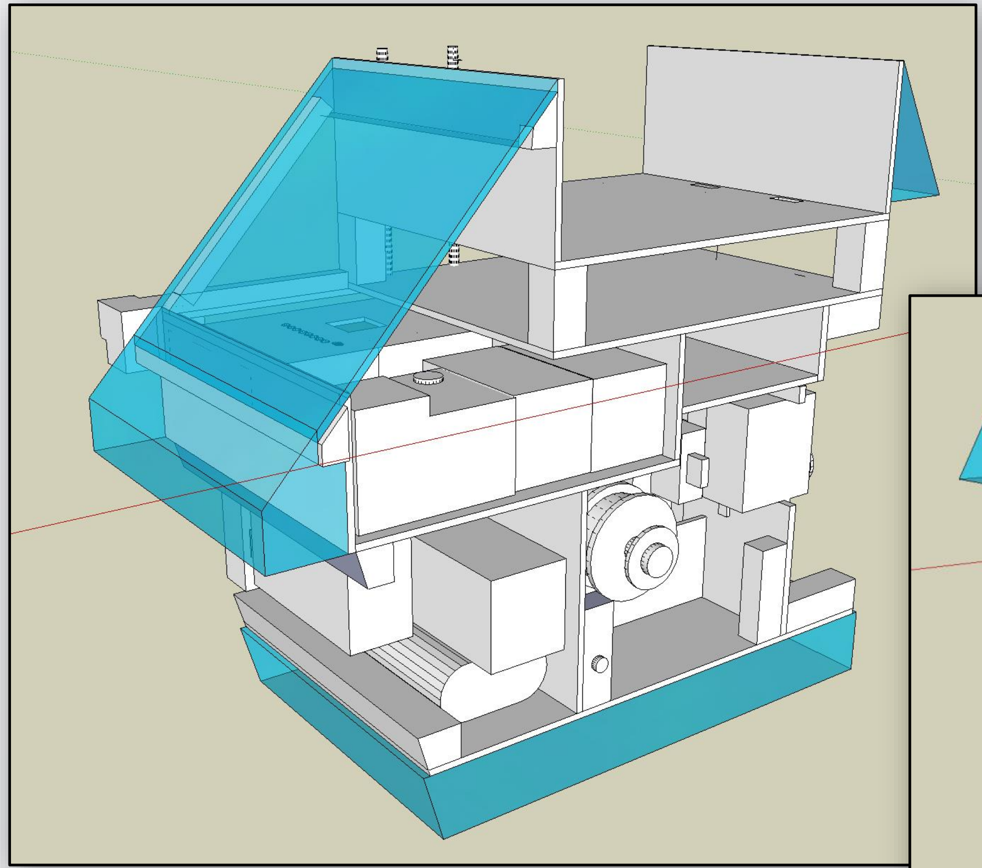
Test thermal properties.

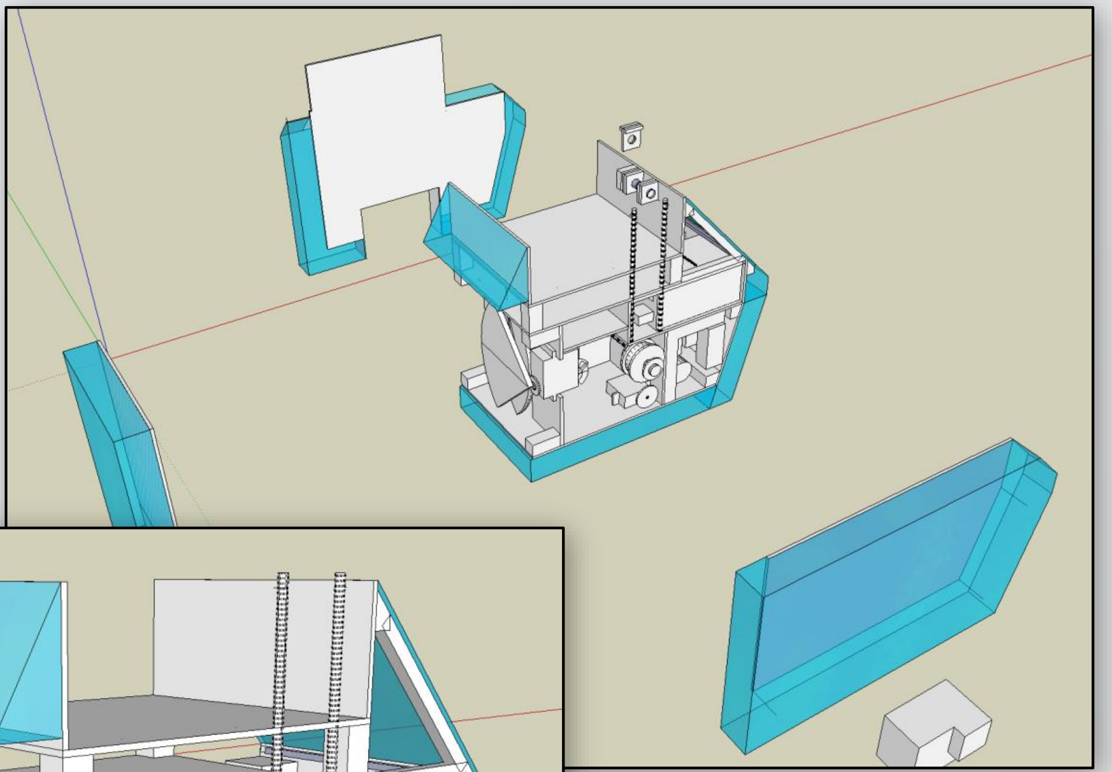
Note: GPS in CPU, SPOT GPS's and Chute are required to face towards sky.

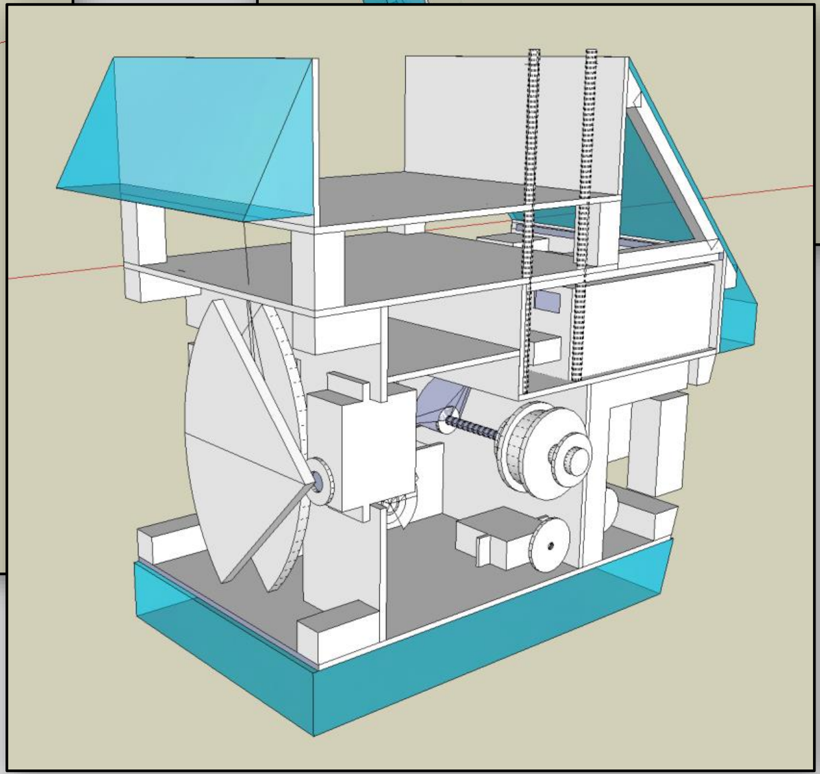
Components in Capsule for Test Drop #5

Capsule Design

Test Drop #5 Capsule

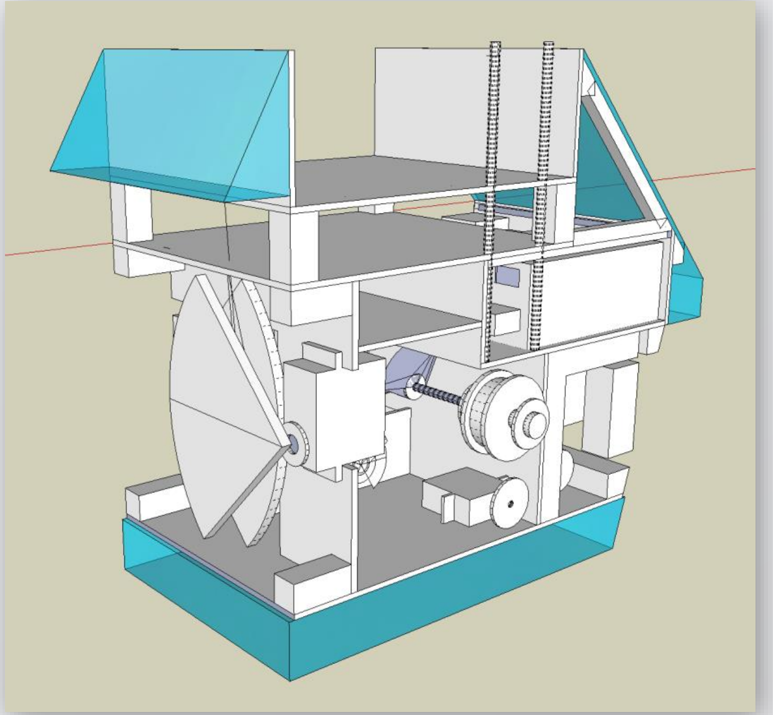


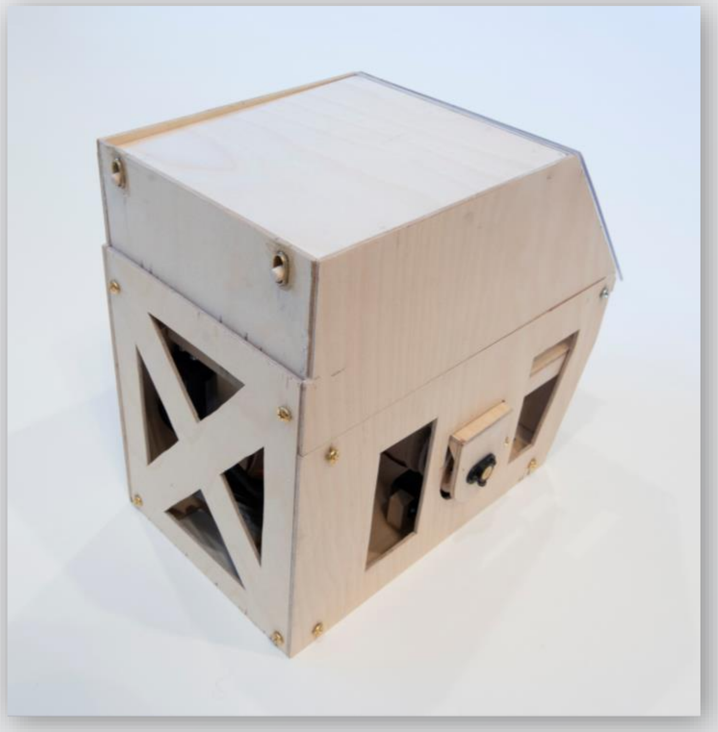


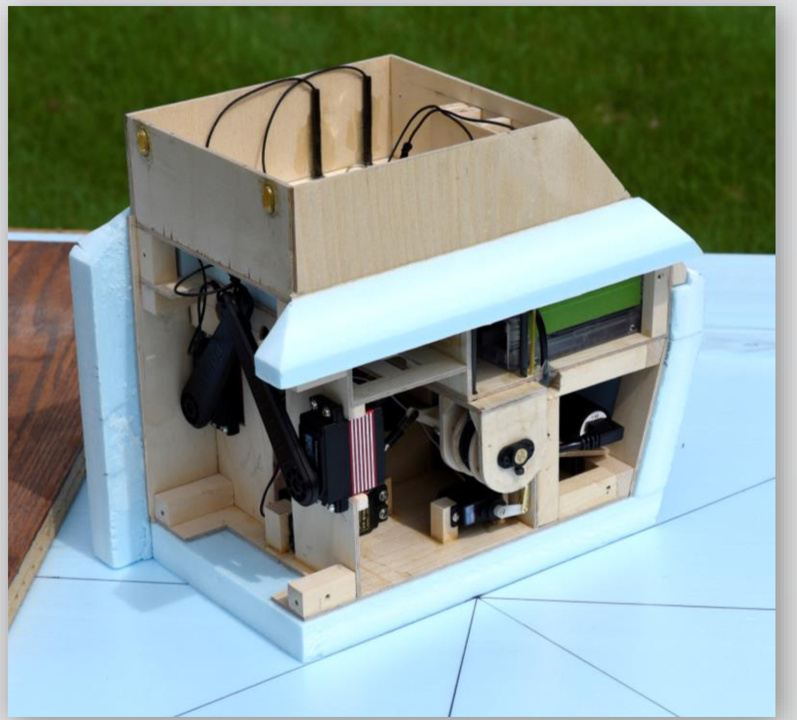


Capsule Design

Test Drop #5 Capsule Design and Construction

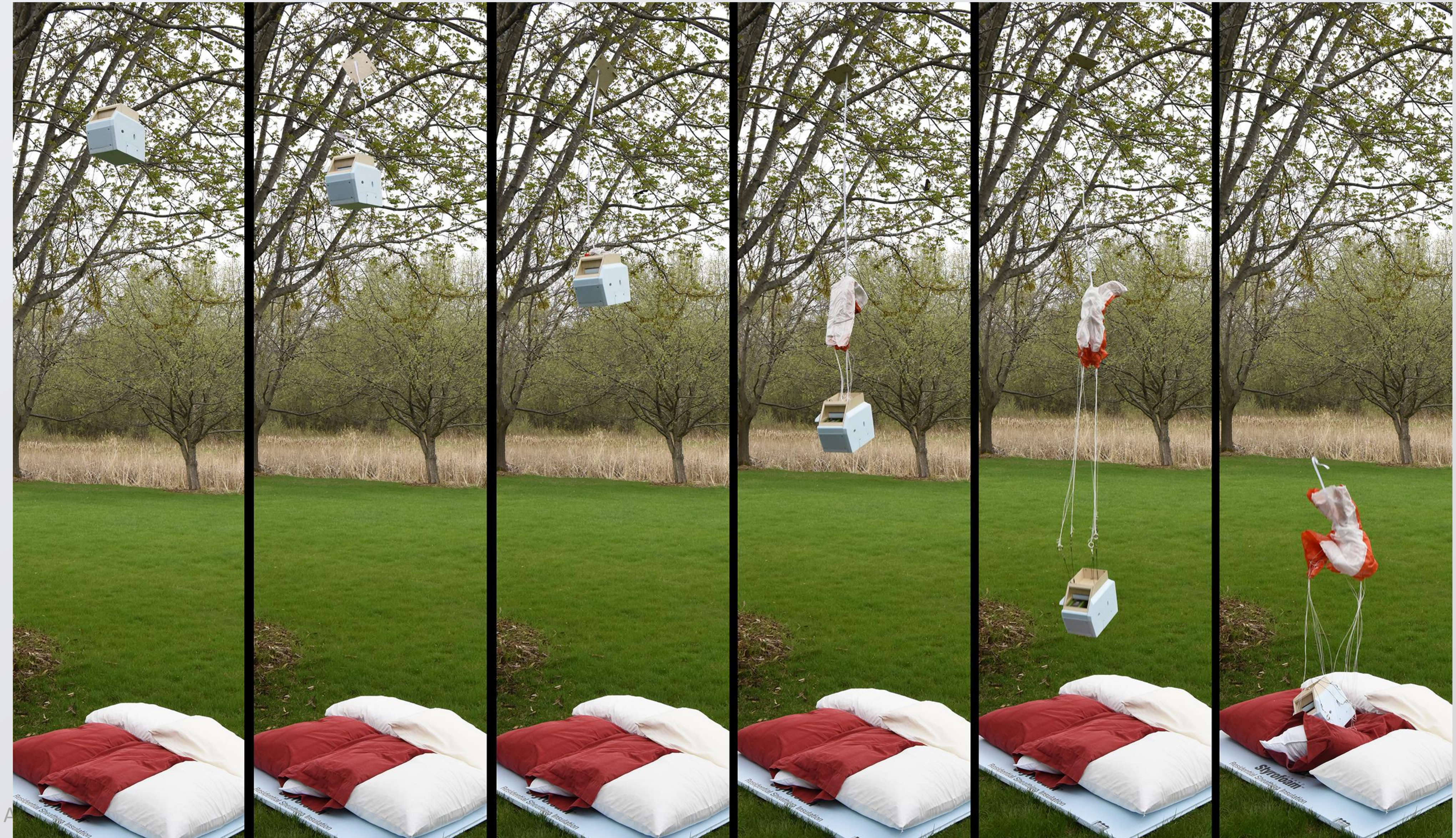






Capsule Design

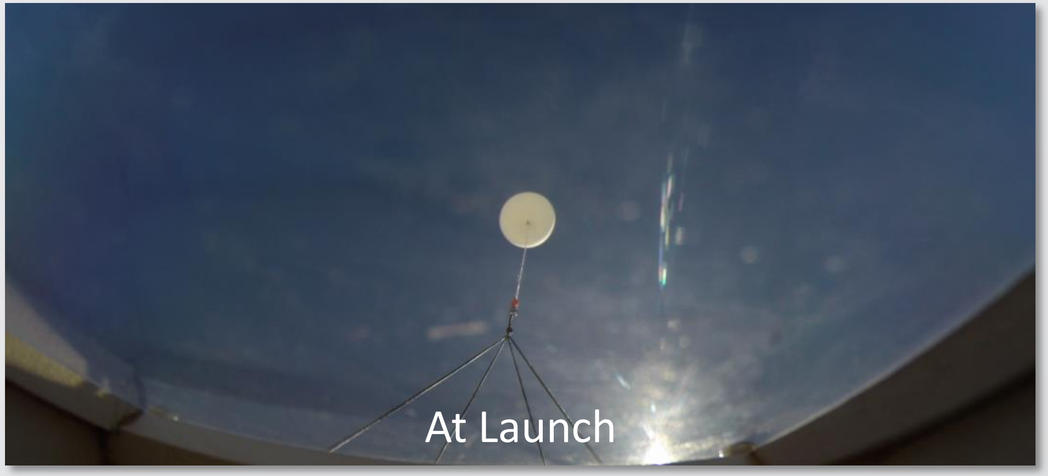
Test Drop #5 - Chute Release Testing

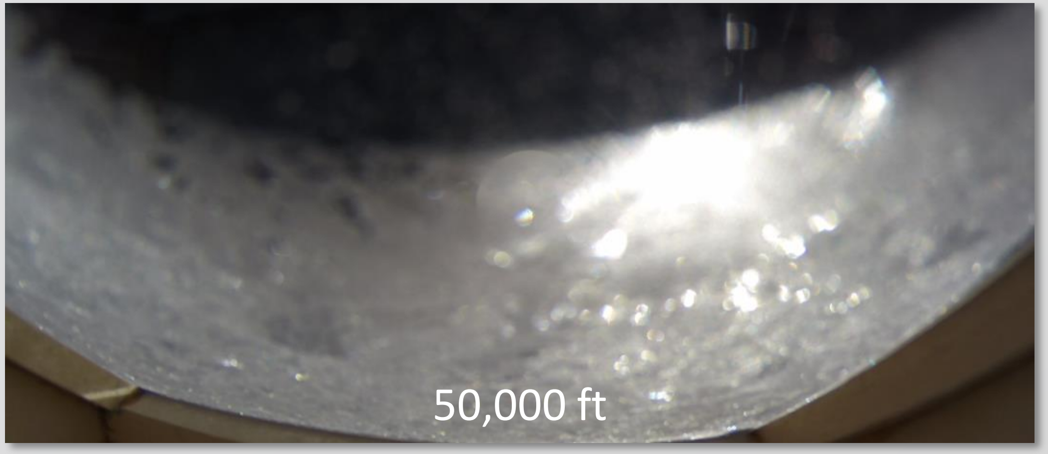


Capsule Design

Test Drop #5 Failure: Icing

MN River Valley from 88,000 ft.





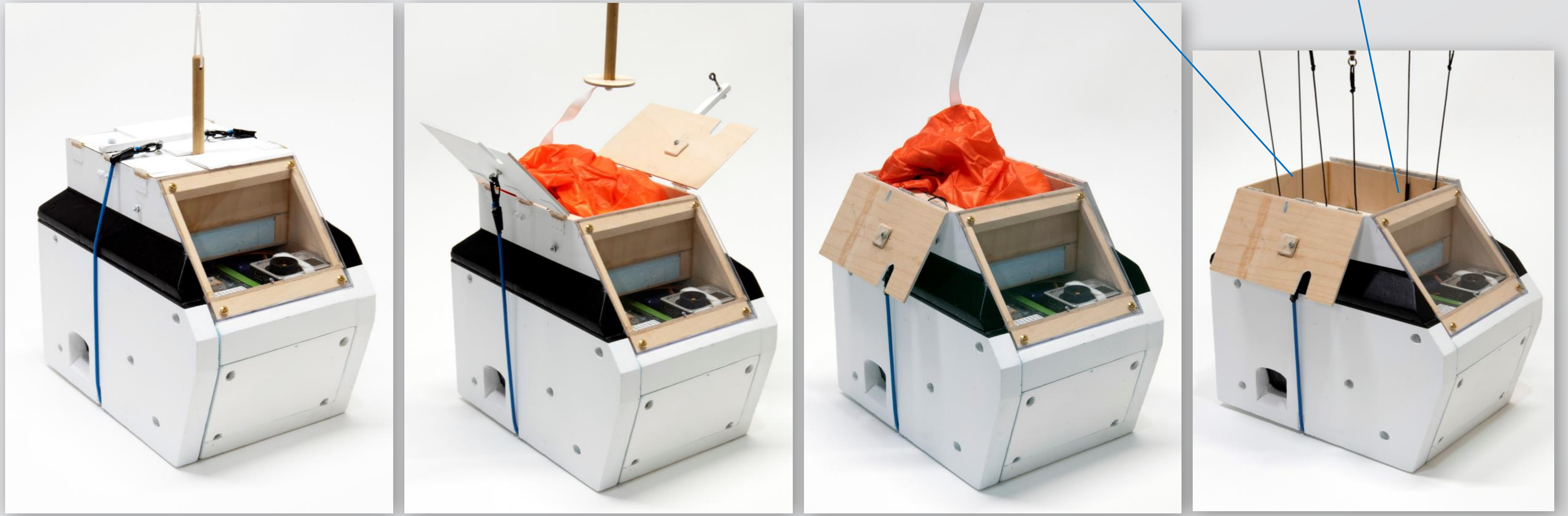
Chute release mechanism jammed. Balloon accented to 88,000 ft.

Capsule Design

Test Drop #6 Capsule
Re-designed Chute and Balloon Release

Control Lines tied to servos

Left and Right Side Harness. Can be pitched forward (nose down 3-5 degrees) for test.



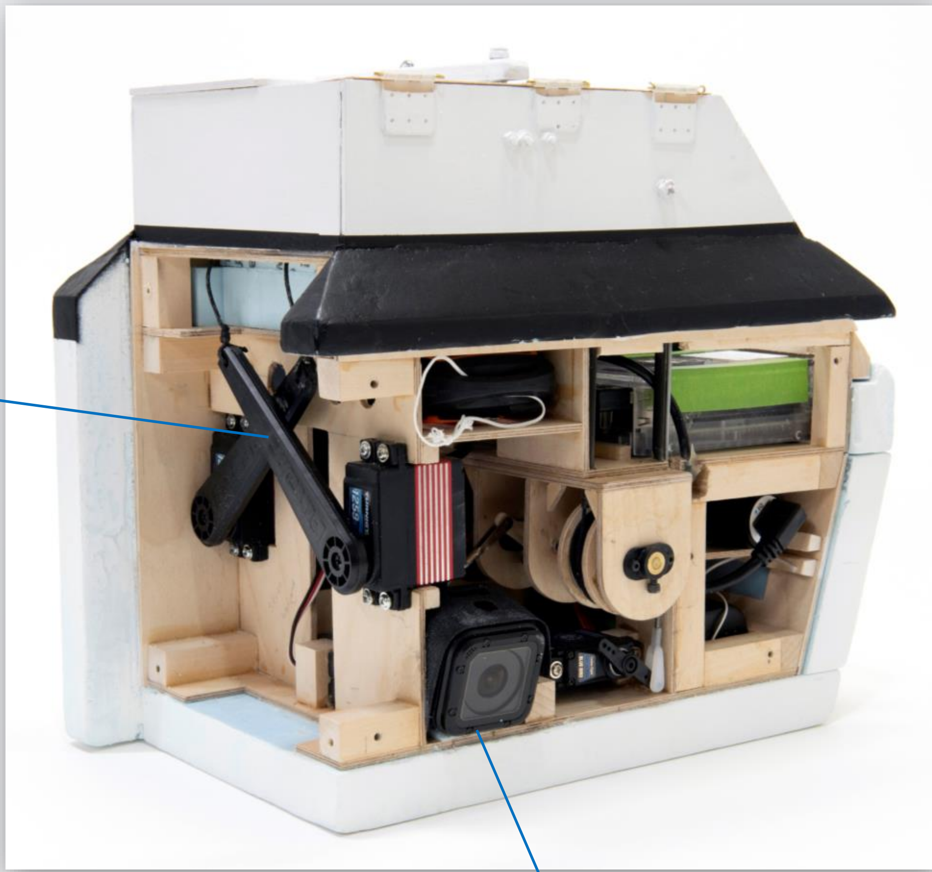
Capsule Design

Test Drop #6 Capsule

Steering Servos

Left turn: Chute's right control line is neutral & left control line is pulled down.

Right Turn: Chute's left control line is neutral and right control line is pulled down.



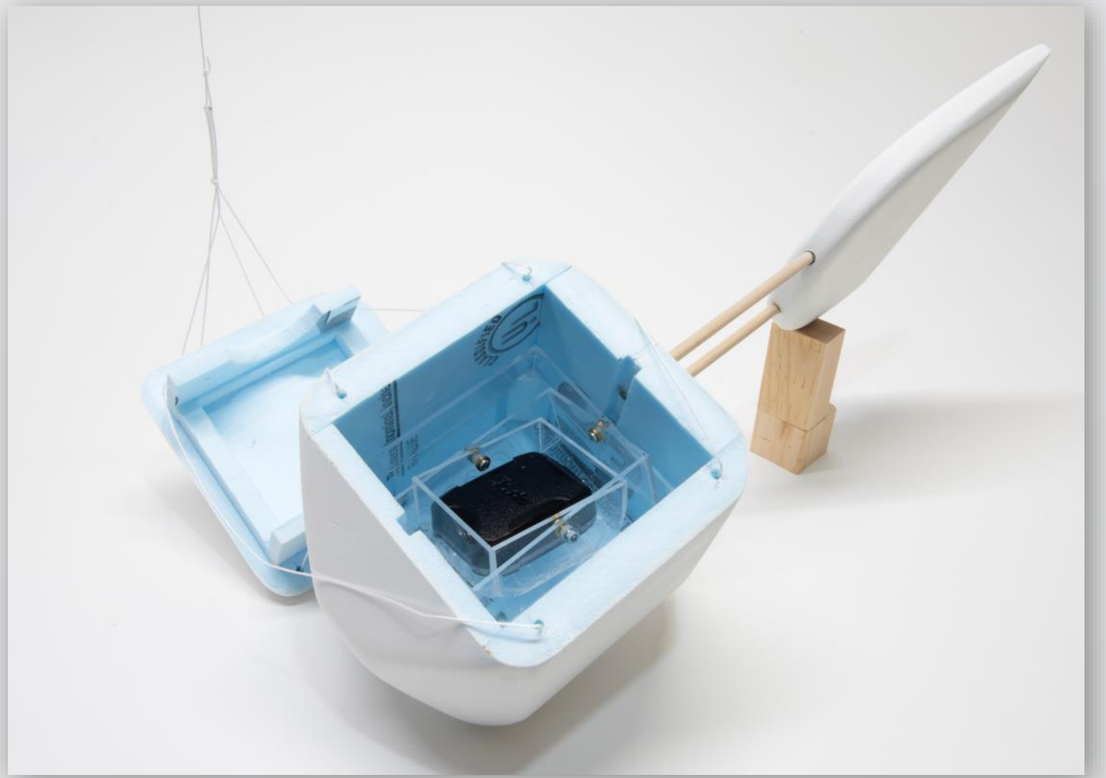
Top Camera

Side Camera

CPU, GPS, Magnetometer

Capsule Design
New Gimballed SPOT GPS Tracker

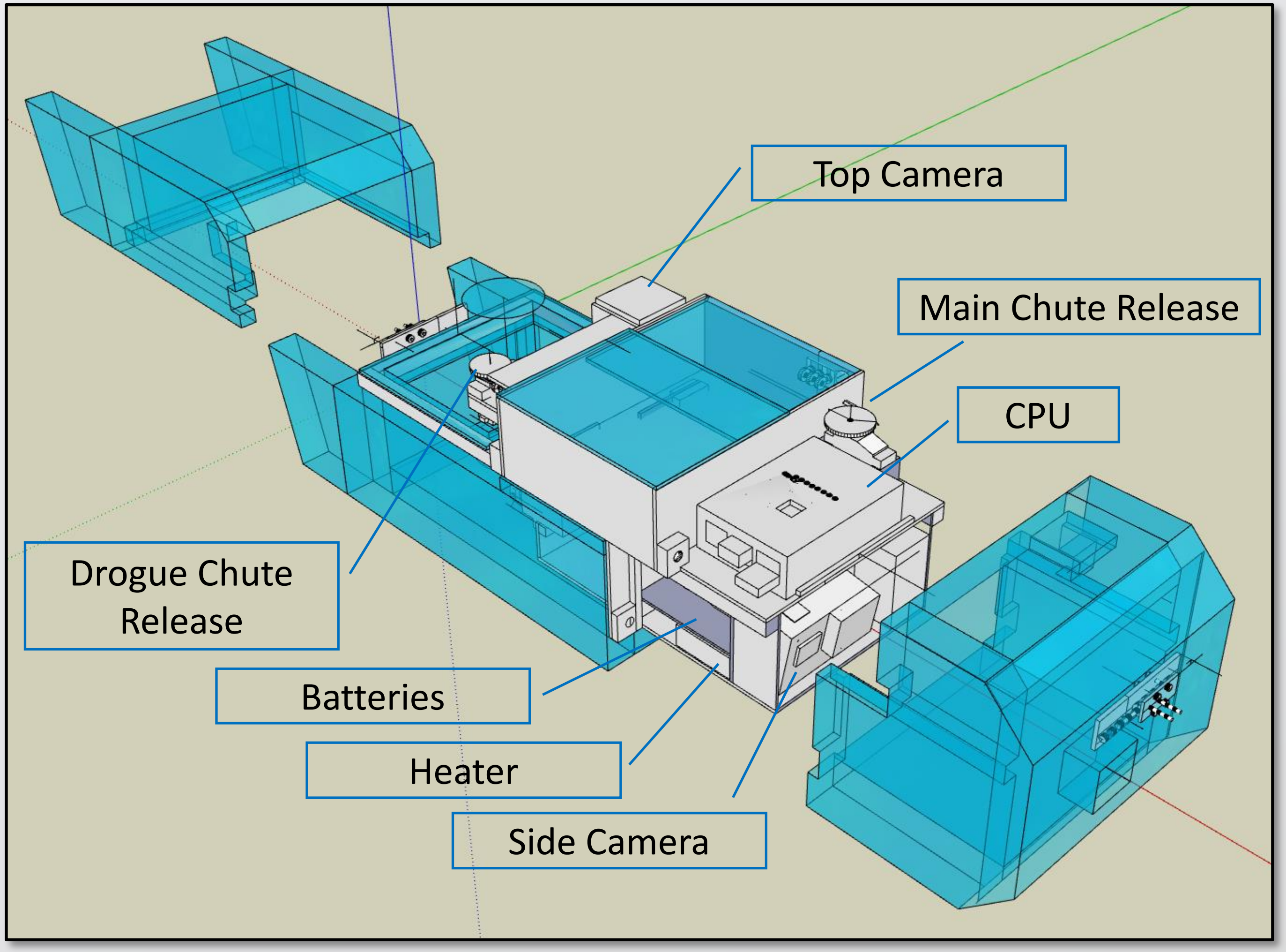
SPOT Capsule hung from bottom of Main Capsule.



SPOT Tracker always faces towards sky.

Capsule Design
Test Drop #7 Capsule

- Integrated Gimbaled GPS Tracker
- Drogue Chute Release Added



Capsule Design
Test Drop #7 Capsule

- Integrated Gimbaled GPS Tracker
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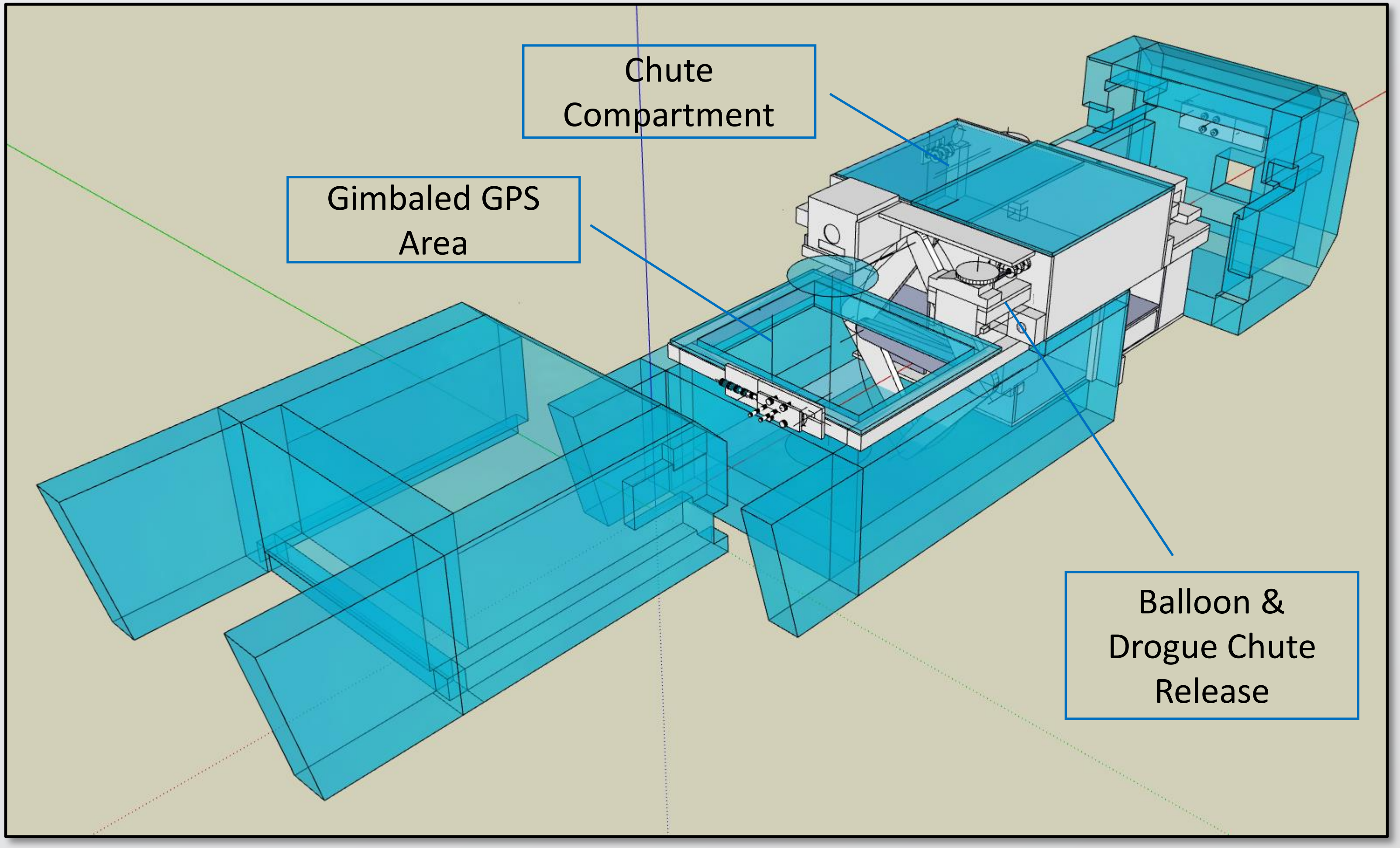

Project Status

Testing to Date

Test Drop	Config	Goal	Results
1	Chute #1 with servo control	Would chute open. Basic flight characteristics.	Successful ✓
2	Chute #1 with servo control	Flight Characteristics	Too Windy
3	Chute #1 with servo control	Flight Characteristics	Able to turn left and right ✓
4	Chute #1 dropped from 5,000 ft.	Land on target from 5,000 ft.	Successful ✓
5	Faster chute #2, new capsule, and heavier. To release at 35,000 ft.	Land on target from 35,000 ft.	Release jammed
6	Repeat of Drop #5 with new chute release mechanism.	Test chute release from 17,000 ft.	Successful ✓
7	Redesign capsule for 100,000 ft. Add drogue chute.	Land on target from 100,000 ft.	Pending