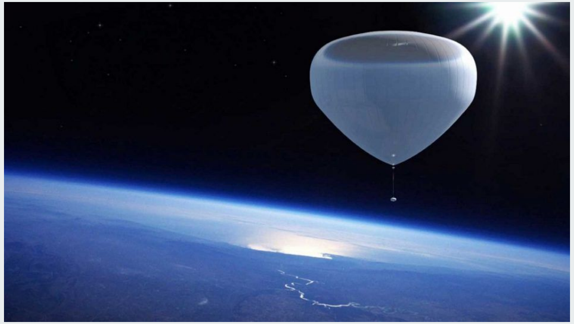
Balloon Design Lab



Group 3

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Design Requirements

Requirements

- Remain at 25km (∓ 1km)
- Minimum of 24 hrs
- 500 kg payload (research instruments)
- Factor of safety reasonable and consistent with other projects: 1.45

Brief Design Overview

Design overview

- Final balloon size: 15.68 m radius
- Lifting gas: Helium
- Material: Thermoplastic Polyurethane Film
- Total weight: 614.54kg
- Balloon thickness: 0.00284mm
- Balloon Coating: Z93 white paint produced by AZ Technology

Design Research

Polyurethane shell

- Balloon is made of Thermoplastic Polyurethane Film
- “The most promising polymeric materials were found to be polyolefin, polyurethane, ethylene propylene diene monomer (EPDM) rubber, and silicone rubber.” - American Institute of Aeronautics and Astronautics

Reflectivity

- Z-93 white paint (reflects ~13% of solar radiation)
- Caused change in density of balloon shell: rho of paint = 2,200 kg/m^3
- Increased mass of shell by ~10kg
- Increase mass of the system ~ 14kg
- Applied in vertical stripes to minimize effects of cracking
- $460/ quart

Helium Propellant

- Less dense than air, relatively inexpensive and not highly flammable
- Well tested in many experiments
- Scale Model

Design Specifications

Code

Possible increase of up to 80°K

Altitude restriction of ∓ 1km

Factor of Safety: 1.45

Maximum increase in temp of Helium 37.6° K

Planned increase in temperature of helium: 26°K.

Minimum reflectivity of balloon: 67.5%

Under normal (night-time) operating conditions the following values apply:

Radius: 15.49 m
Volume: 15571.51 m^3
Mass of Shell: 29.61 kg
Mass of Helium: 84.93 kg
Mass of Payload: 500 kg
Total Payload: 614.54 kg
Temperature of Helium: 221.65 K

Under maximum (daytime) operating conditions these are the new Values:

Radius: 15.68 m
Volume: 16133.27 m^3
Mass of Shell: 29.61 kg
Mass of Helium: 84.93 kg
Mass of Payload: 500 kg
Total Payload: 614.54 kg
Temperature of Helium: 247.65 K

Scale Model vs. Full-Scale Ballon

	Radius	Shell Mass	Payload	Volume	Expanded Volume
Scale Model	17.15 cm	9.553 g	1.54 g	12879 cm^3	19353 cm^3
Full-Scale	15.30 m	10.12 kg	500 kg	14998 m^3	16758 m^3

Zero Pressure Balloons vs. Super Pressure Balloons

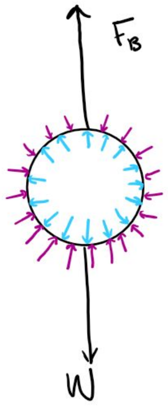
- Ballast system to keep Zero Pressure Balloon at specified altitude (fluctuates)
- Super Pressure don't allow change in volume to stay at altitude (level)

Assumptions

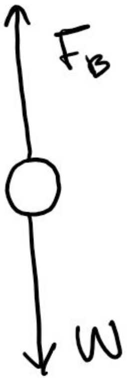
- Perfectly Spherically Shaped
- No Forces due to launching/Reaching Elevation of 25 km
- Only Forces are Weight Force and Buoyant Force
- The 500 kg payload includes any tethering mechanisms
- The gas can’t escape the balloon shell (no leaks)

Design Analysis

Free Body Diagram



Local FBD



Global FBD

$P_{external}$

$P_{internal}$

F_B = buoyant force

W = weight force

$$\Downarrow$$

$$W = (m_{shell} + m_{payload} + m_{gas})\,g$$

$$\Sigma F_y = ma$$

$a = 0$ (not moving)

$$0 = F_B - W \implies F_B = W$$

$$\rho_{atm}\,\cancel{g}\,V = (m_{shell} + m_{gas} + m_{payload})\,\cancel{g}$$

$$\rho_{atm} = \frac{m_{shell} + m_{gas} + m_{PL}}{\frac{4}{3}\pi r^3}$$

Volume and Buoyancy

$$\rho_{atm} = \frac{m_{payload} + m_{shell} + m_{He}}{\frac{4}{3}\pi r^3}$$

$$\rho_{shell} = \frac{m}{V} = \frac{m}{SA \cdot t} = \frac{m}{4\pi r^2 \cdot t} \qquad \rho_{shell} = \frac{m}{4\pi r^2 \cdot t}$$

$$m_{payload} = 500kg \qquad m_{shell} = \rho_{shell} \cdot t \cdot 4\pi r^2$$

$$m_{He} = \rho_{He} \cdot \frac{4}{3}\pi r^3$$

Volume and Buoyancy

$$\rho_{atm} = \frac{m_{payload}+m_{shell}+m_{He}}{\frac{4}{3}\pi r^3}$$

$$PV = nRT \qquad P = \rho_{He} R_{specific} T \qquad \rho_{He} = \frac{P}{R_{spec} T}$$

$$r = \sqrt[3]{\frac{m_{payload}}{\frac{4}{3}\pi(\rho_{atm}-\rho_{He})-\rho_{shell}\left(\frac{2\pi\cdot P_g \cdot F.S.}{Y.S.}\right)}}$$

$$t = \frac{P_g r}{2\sigma} \qquad \sigma = \frac{Y.S}{F.S.} \qquad t = \frac{P_g \cdot r \cdot F.S.}{2\cdot Y.S.}$$

$$V = \frac{4}{3}\pi r^3$$

$$m_{shell} = \rho_{shell}\left(\frac{2\pi\cdot P_g \cdot F.S.}{Y.S.}\right)$$

Final Mass Budget

Our Design

- The Balloon does not have a ballast system or venting gas.
- With the use of Z93, the amount of energy entering the balloon system is lowered
- This keeps our balloon within the 25 ± 1 km altitude
- Mass = 614.54 kg

Scale Model

- The scale model had no release of gas or ballast system
- Final mass equaled Initial mass
- Mass = 12.641 g

Performance Subject to Radiation

Design Decisions

- After using radiation equations a given absorption keeps balloon in altitude range
- Researched many highly reflective materials
  - Silvered teflon
  - BoPET
  - Aluminized Kapton
- We choose Z93 because it had a high reflectivity of 87% while still being manufactured
  - Paint could be easier to work with

Assumptions, Equations, Processes

- Z93 coating would offer 87 percent reflectivity
- The Balloon is launched at sunset on winter solstice
- Constant Mass (Z93 degradation)
- Z93 adheres to polyurethane shell without need for primers

Processes:

- A spray painting gun is used to apply the Z93 to our specified thickness across a fully inflated balloon.

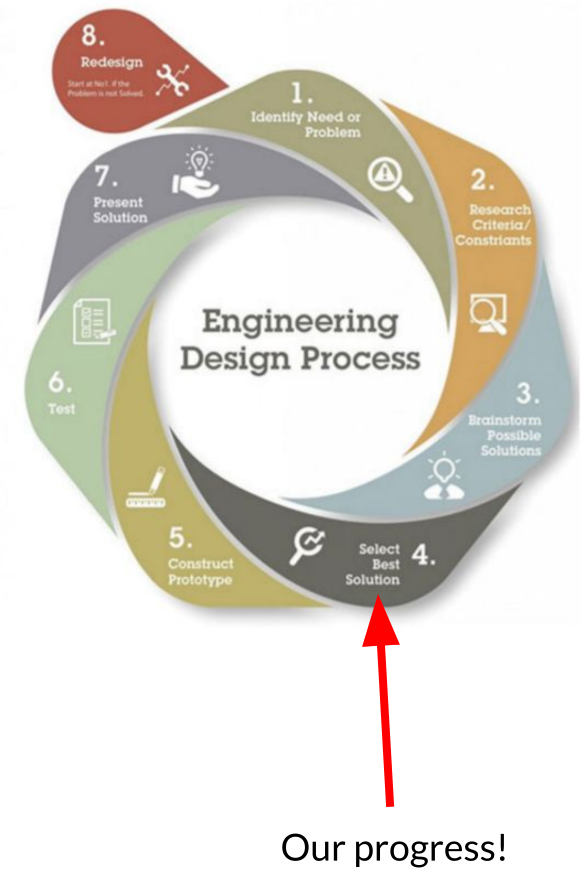
Design Deliverables

Further Research

- Weather conditions
- Recovery system
- Increasing time aloft
- Material Design

Findings

- Our design is theoretical and would need scale model testing before it could be cleared.
- Not bound by cost. We designed our balloon to surpass the design requirements rather than being a cost effective solution.
    - Cost estimate:
- Our beginning research was not adequate to have an understanding of the entire project.
- Decisions were made and changed multiple times.
- Final Decisions
    - Thermoplastic Polyurethane Film (TPU), Z93, and Helium to fulfill the design requirements



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Images

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