BalloonSat Construction

Ideas and Suggestions

L. Paul Verhage

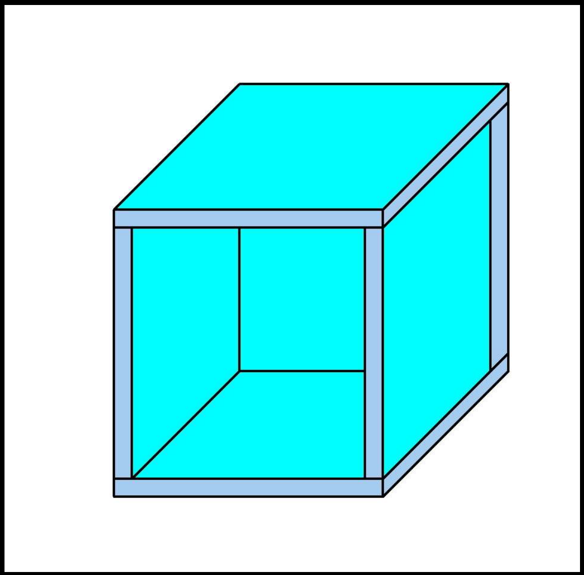
9 July 2013

What is a BalloonSat?

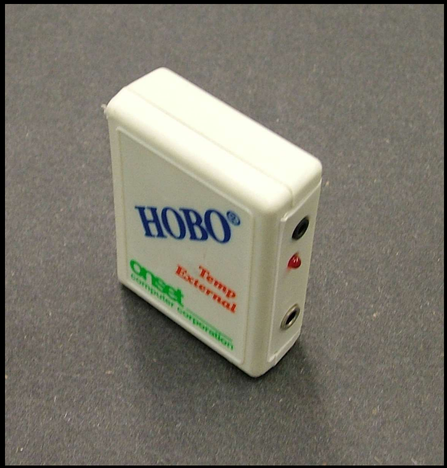
- Functional Model of a Satellite
- Carried by Weather Balloon into Near Space (> 60,000 Feet)
- Carries Experiments (active and/or passive)
- Collects and Returns Data
- Designed for Launch and Descent Conditions
- Exposed to the Near Space Environment

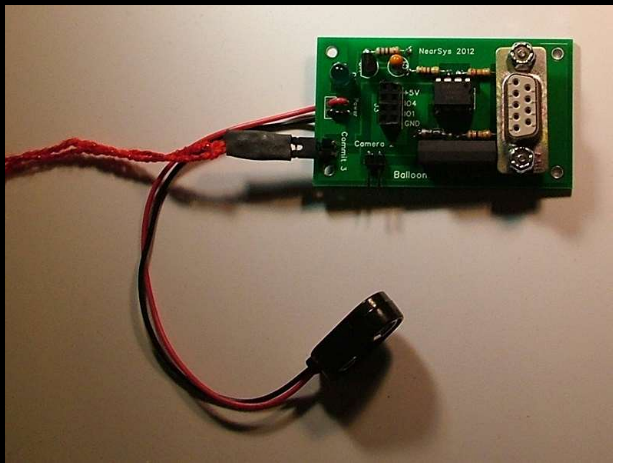
Parts of a BalloonSat

Airframe



Avionics





Possible Design Limitations

- Maximum Weight
- Experiment Requirements
- Minimum Amount of Data and Frequency of Data Collection
- Available Design and Build Time
- Maximum Dimensions

Tools

- Exacto Knife
- Metal Straight Edge
- Right Angle (Triangle or T-Square)
- Ball Point Pen
- Felt-tip Marker
- Hot Glue Gun and Glue Sticks
- Files/Emory Board
- Circle Template
- Screwdriver/pliers
- Hot Knife

Materials

- Styrofoam (various thicknesses)
- Plastic Tubes
- Plastic Lids
- Tape
- Rubber Bands
- Nuts, Bolts, and Washers

Some Design Considerations

- Sufficient volume for datalogger and experiments
- Securely attach components to airframe
- Multiple plastic tubes for tether lines
- Easy access to interior through hatch(es)
- Hatch placement on the side of the airframe, not the top where tethers are located

More Design Considerations

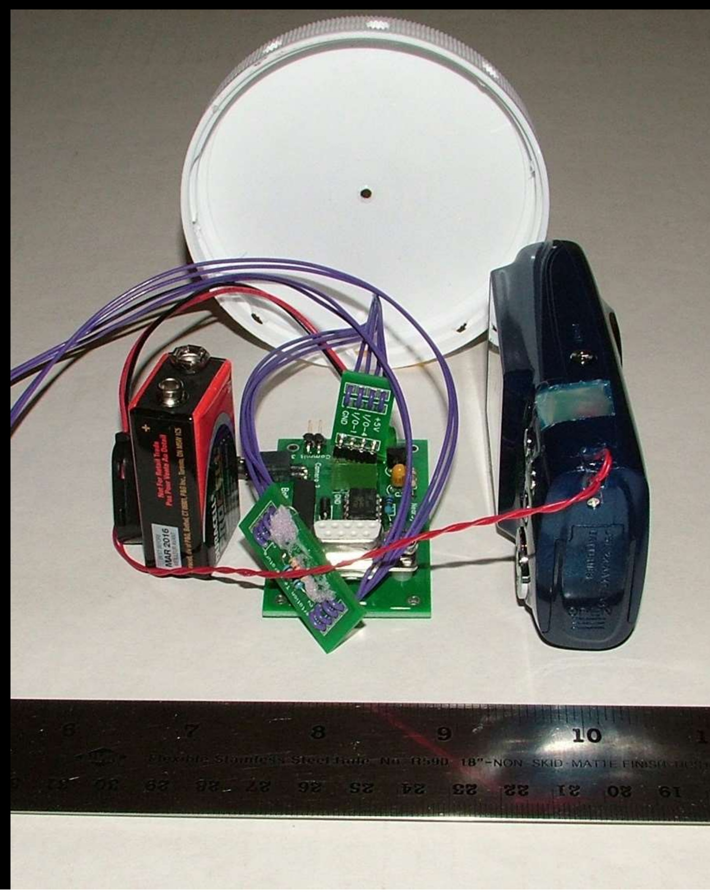
- Minimize airframe openings to minimize cold air infiltration
- Minimize bolt hole diameter and use washer and nylock
- No window over camera opening
- Must function during all phases of the mission
- Quick and simple hatch closure that uses rubber bands
- Cameras do not time-out and switch off

Keep in Mind

- Be aware of design specifications
- Paper design before cutting
- Measure twice, cut once
- Watch glue temperature, don’t melt Styrofoam
- Styrofoam has thickness
- Let function determine shape of BalloonSat

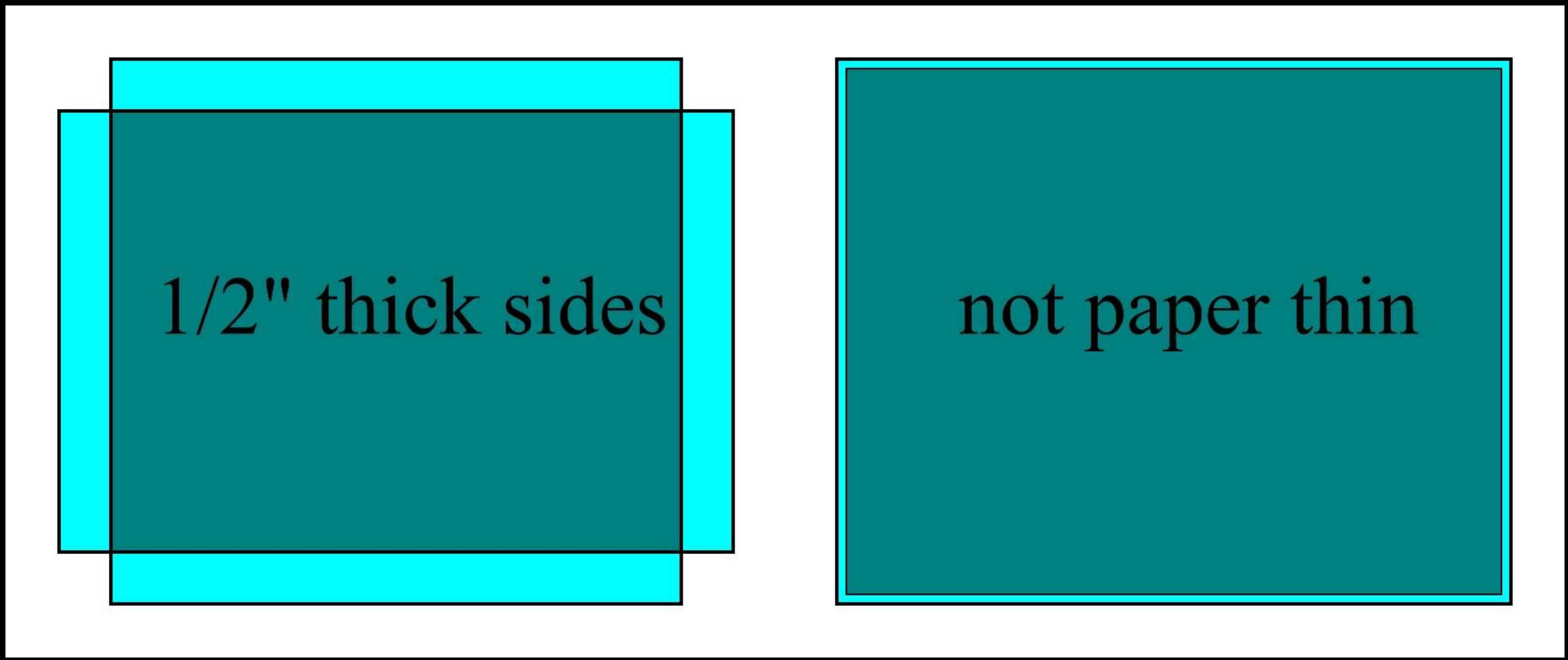
Physical Layout

- Connect and position the components, then measure dimensions



Styrofoam has Thickness

- Take Styrofoam thickness into account when designing the airframe



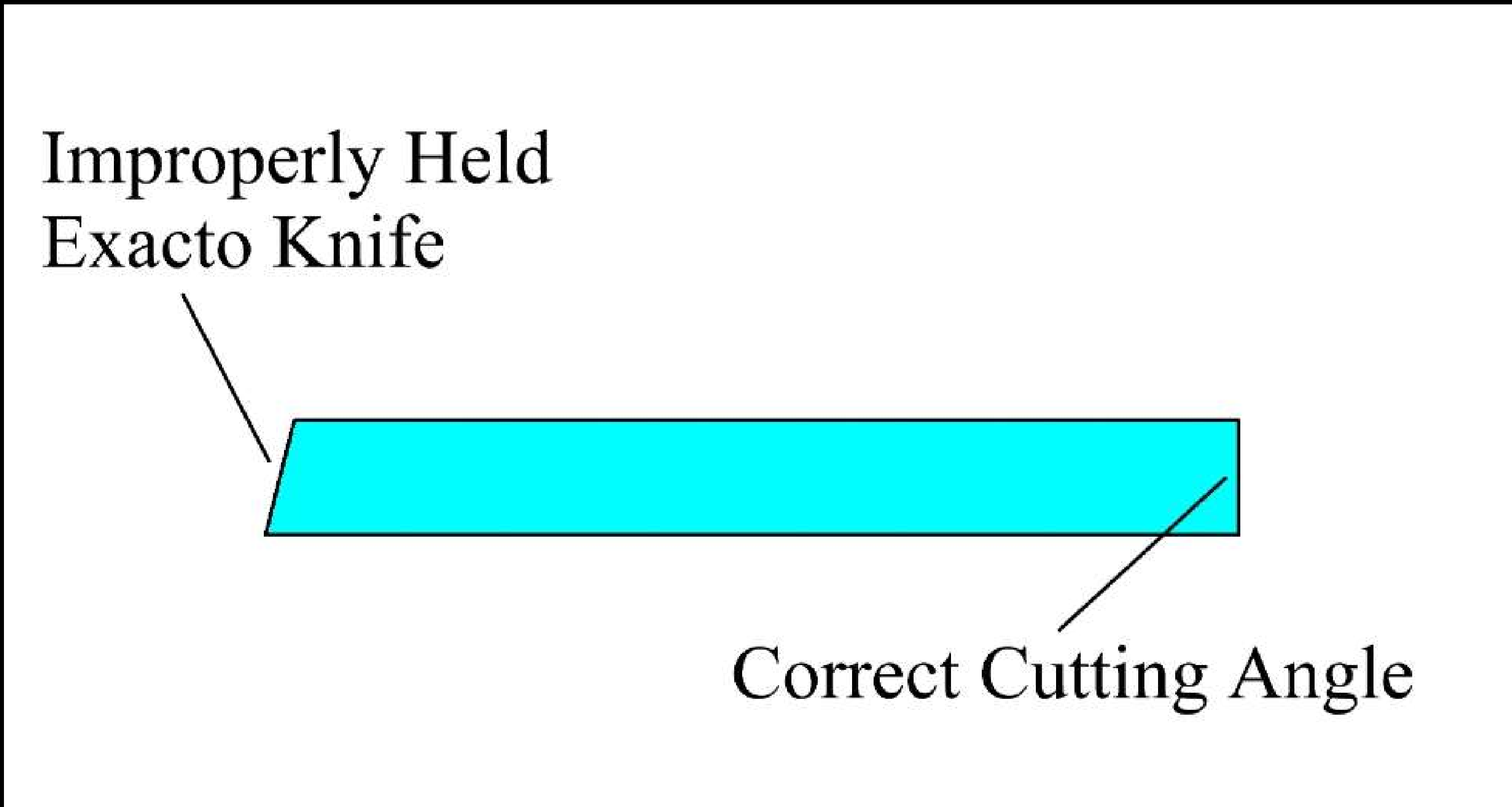
Use a Sharp Exacto Knife

Rough Edge vs Smooth Edge

Use a Metal Straight Edge

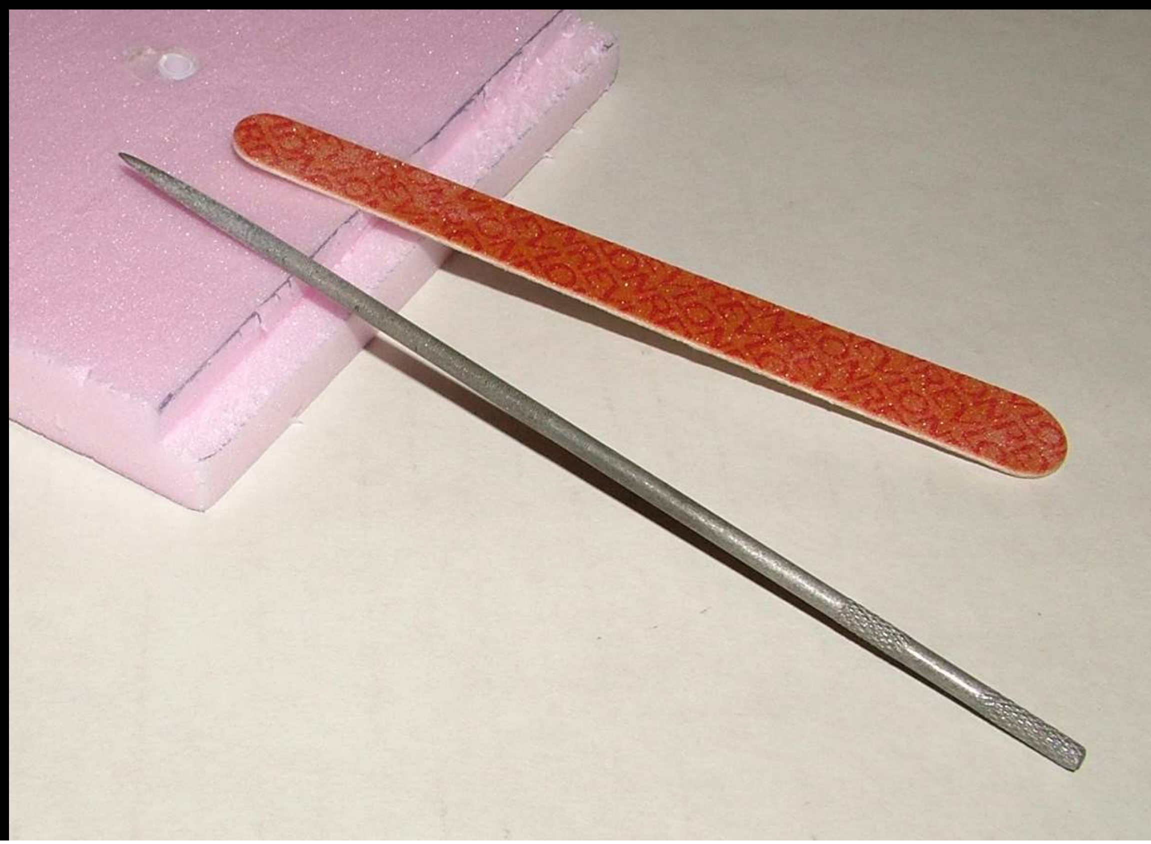
- Wood and plastic rulers get nicked and the lines aren't as straight

What angle is the Exacto knife held while cutting?



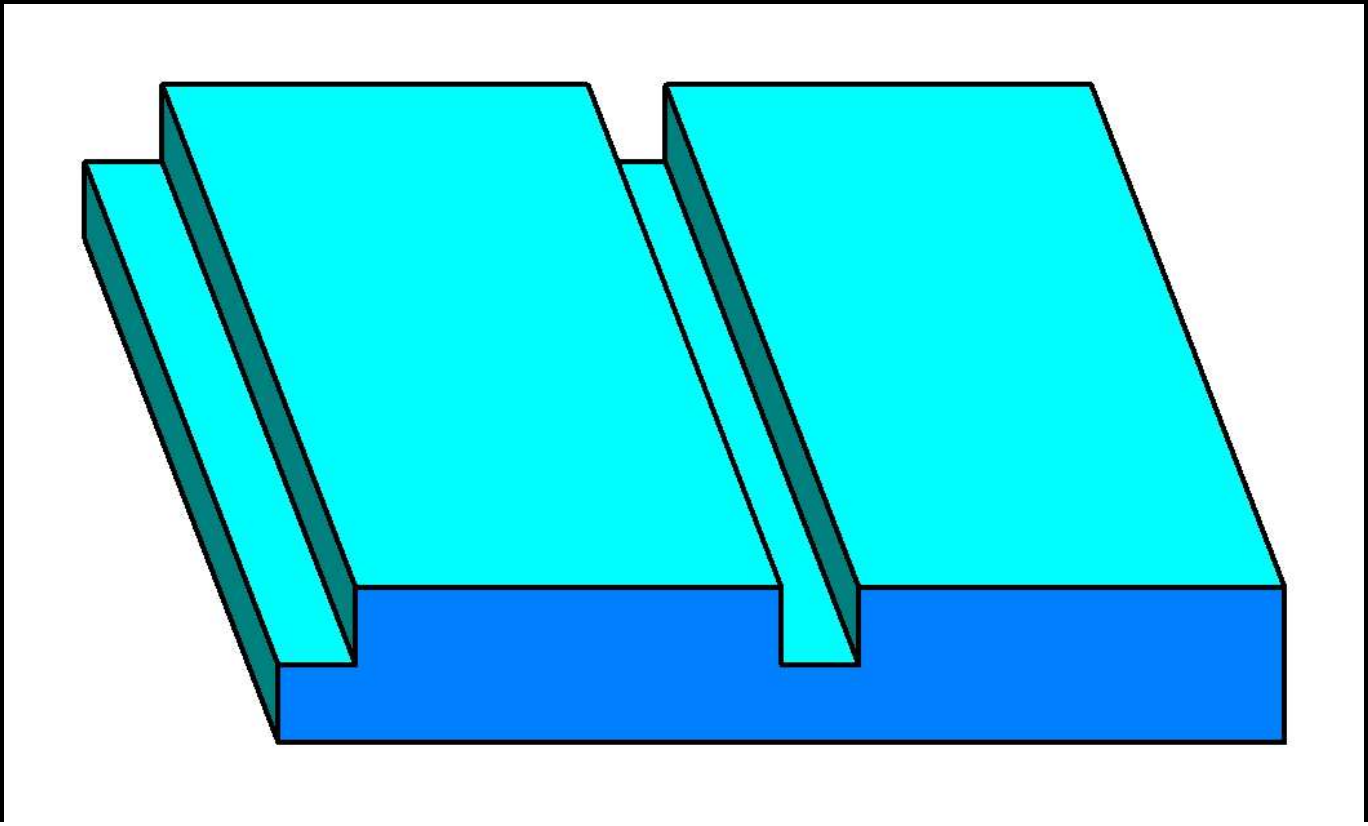
Files and Emery Board

- Smoothes and shapes
- Don’t inhale Styrofoam dust



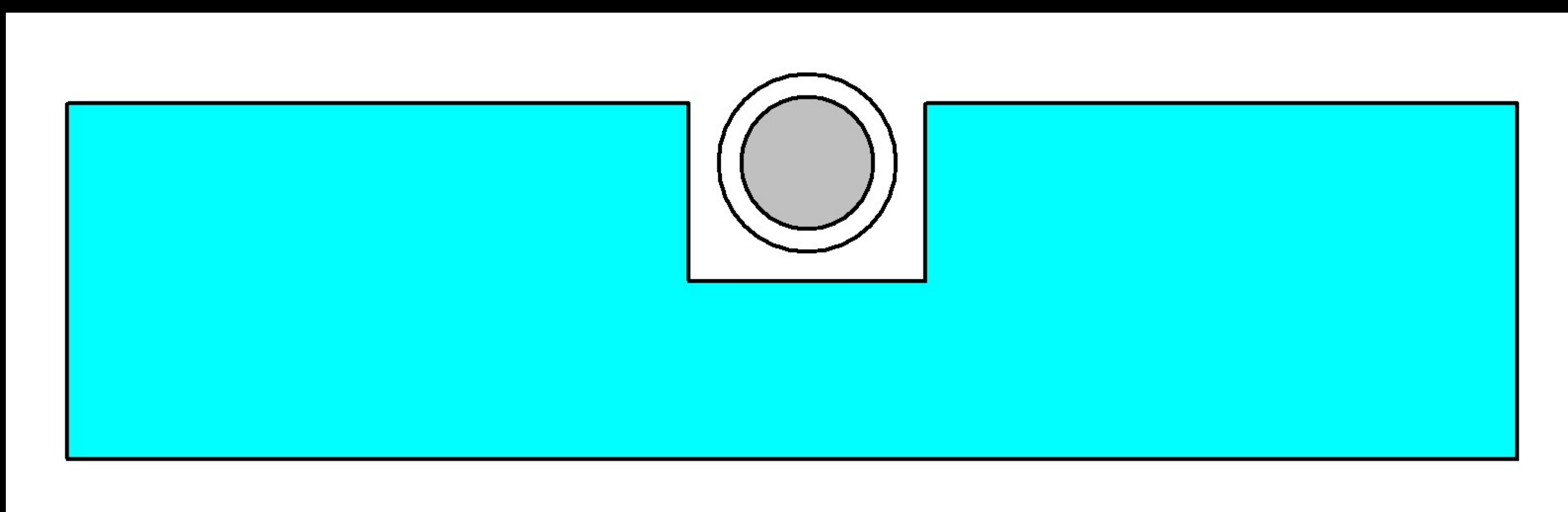
Cutting Slots

- Two parallel lines
- Chip out and file flat



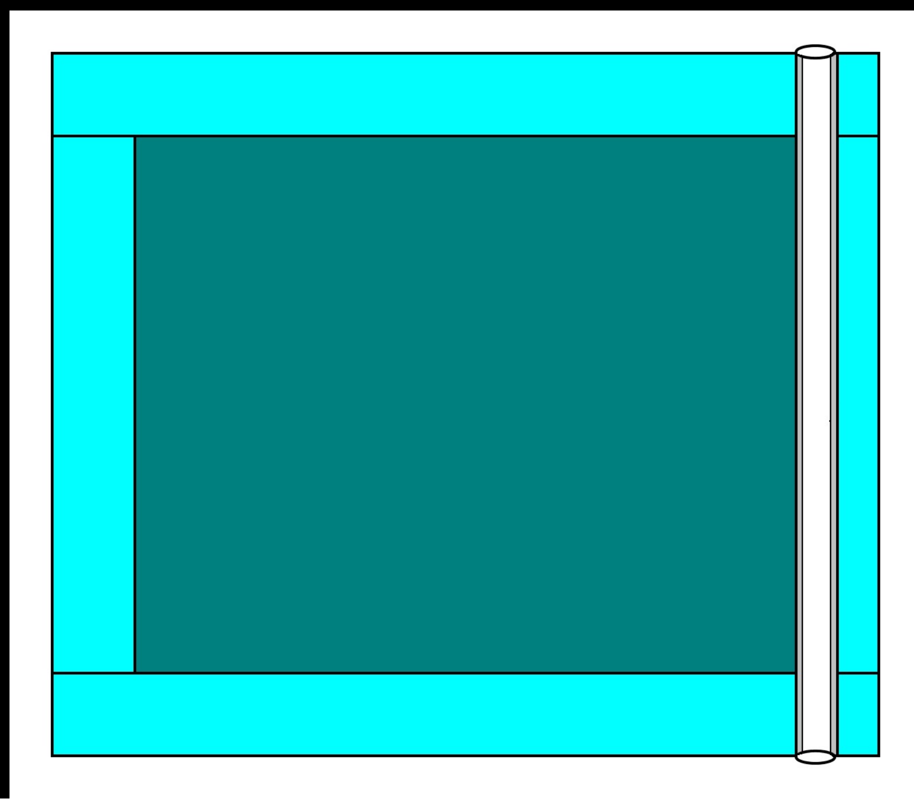
Embed Tubes

- Embed and glue into place for strength
- Interior slots for tether tubes and exterior slots for hatches



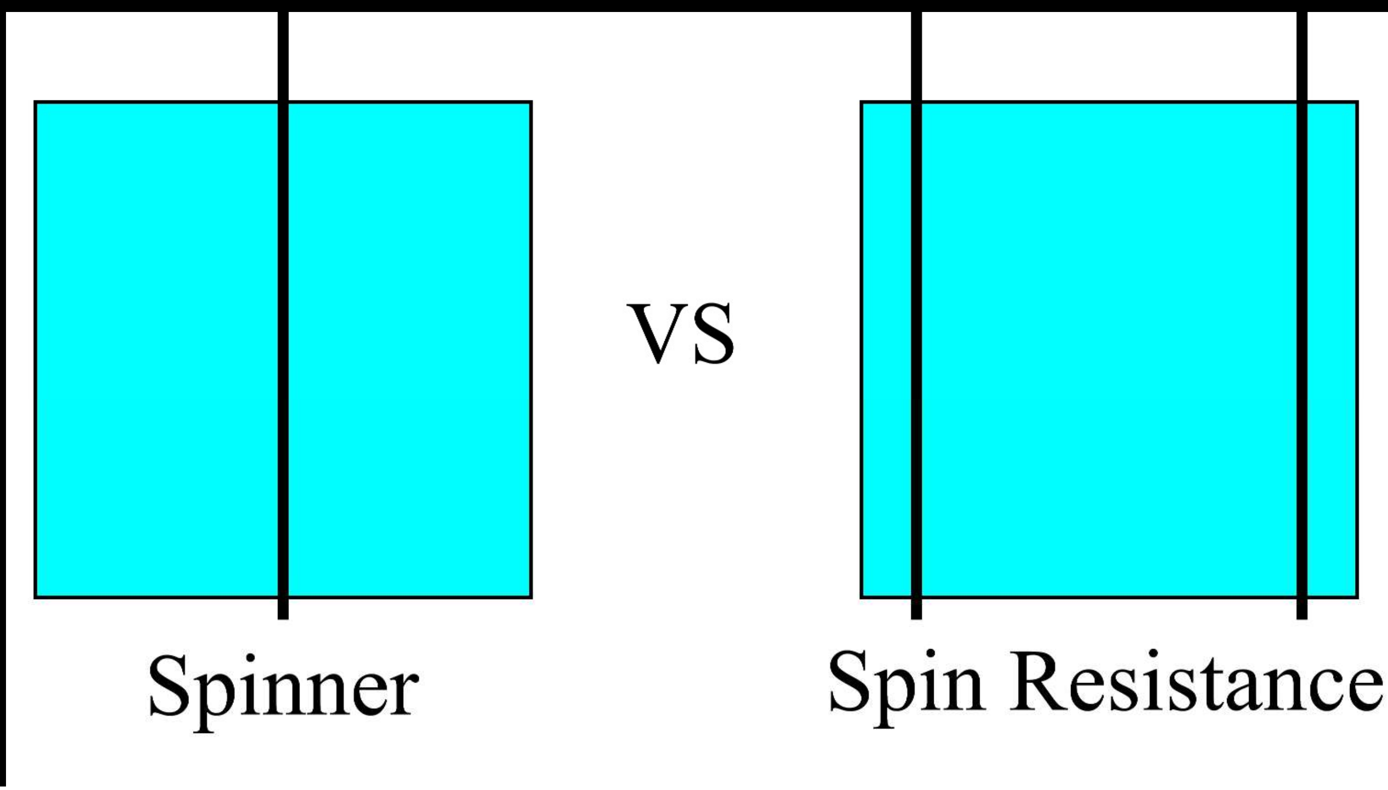
Extend Tether Tube to Airframe Faces

- Tubes protect Styrofoam from being cut by tether



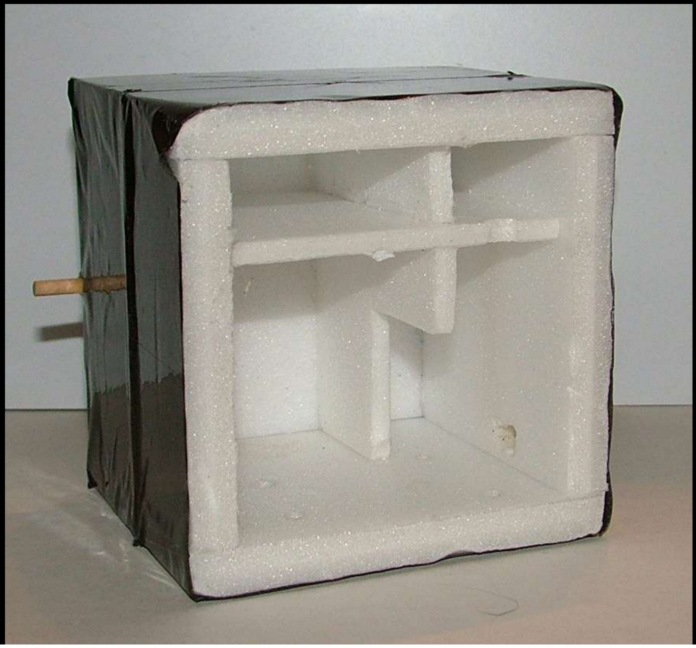
Use Four Tether Tubes

- BalloonSats spin less when they have more than one tether line



Include Battery Box

- Confine battery so it doesn't bounce into items inside the BalloonSat
- Add block of foam rubber inside battery box to fill empty volume and absorb motion



One or Two Hatches?

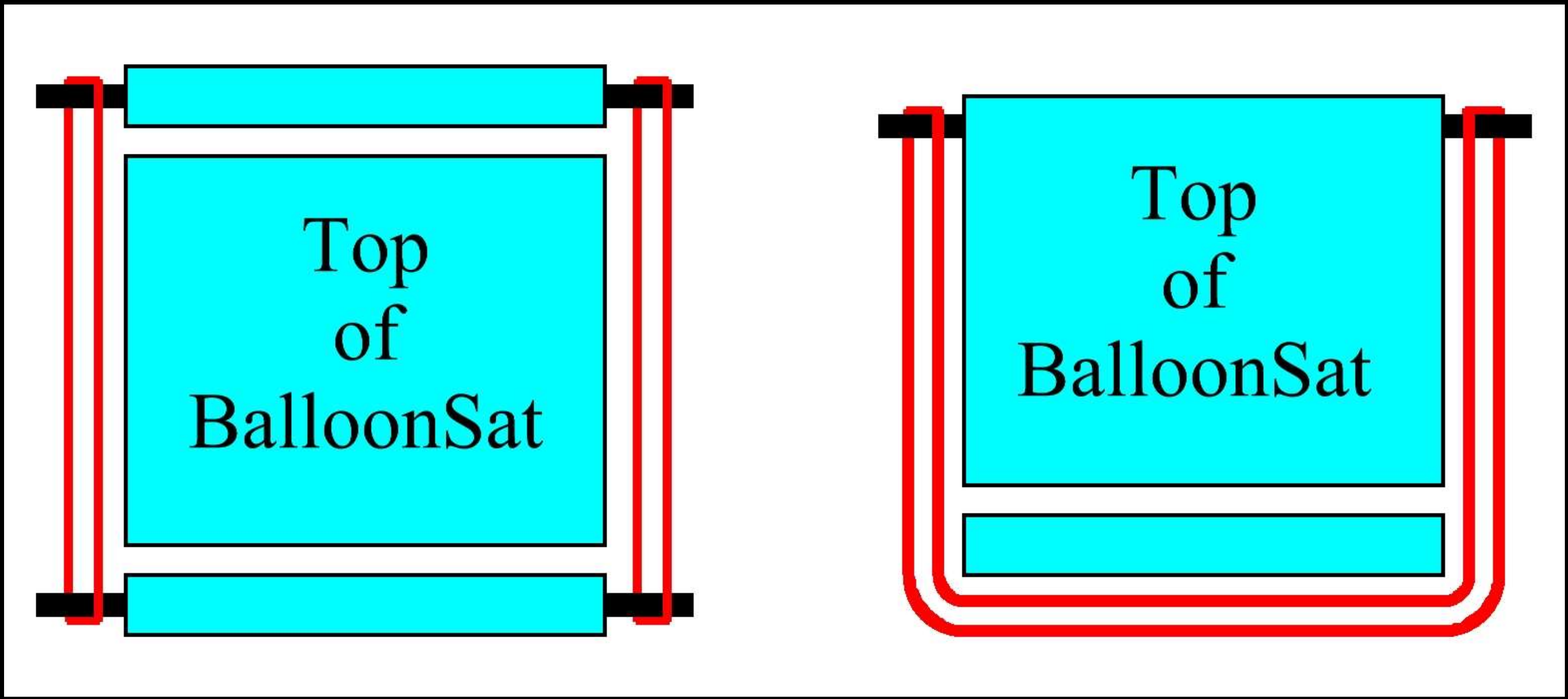
- May be easier to reach into a BalloonSat with two hatches

Hatch Closure

- Stretch rubber band over hatch and wrap around tube(s) extending from airframe

Hatch Closures

- Wrap a rubber band around tubes glued into hatch

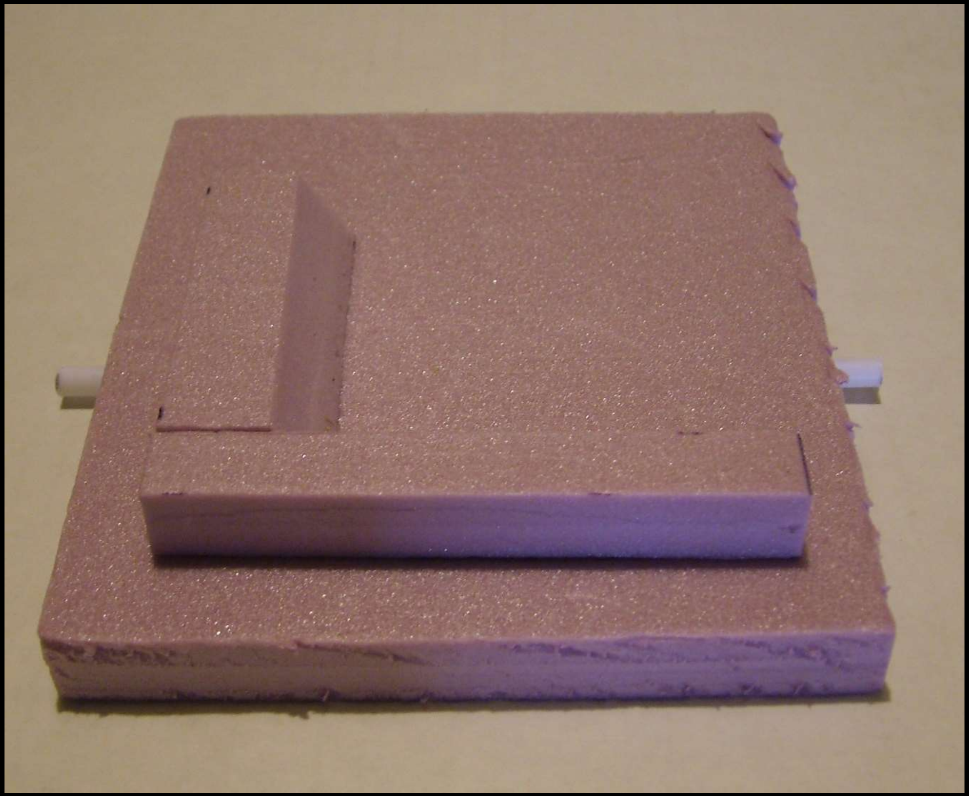


Permanent Airframe Holes

- Passes bolts and rubber bands through wall
- Insert and glue a plastic tube

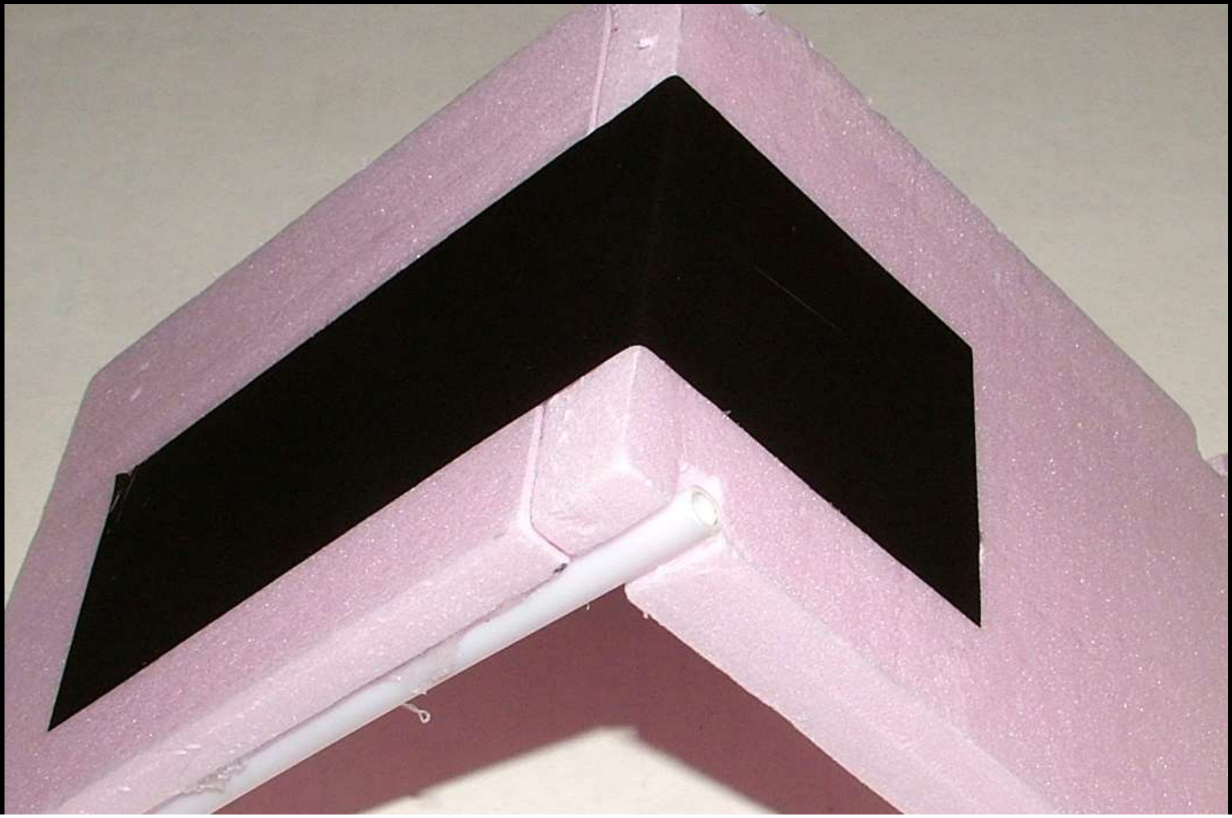
Alignment Blocks on Hatches

- Positive lock
- Prevents hatch from sliding around



Wrap Airframe in Tape

- Compression helps hold airframe together
- Adds color to BalloonSat

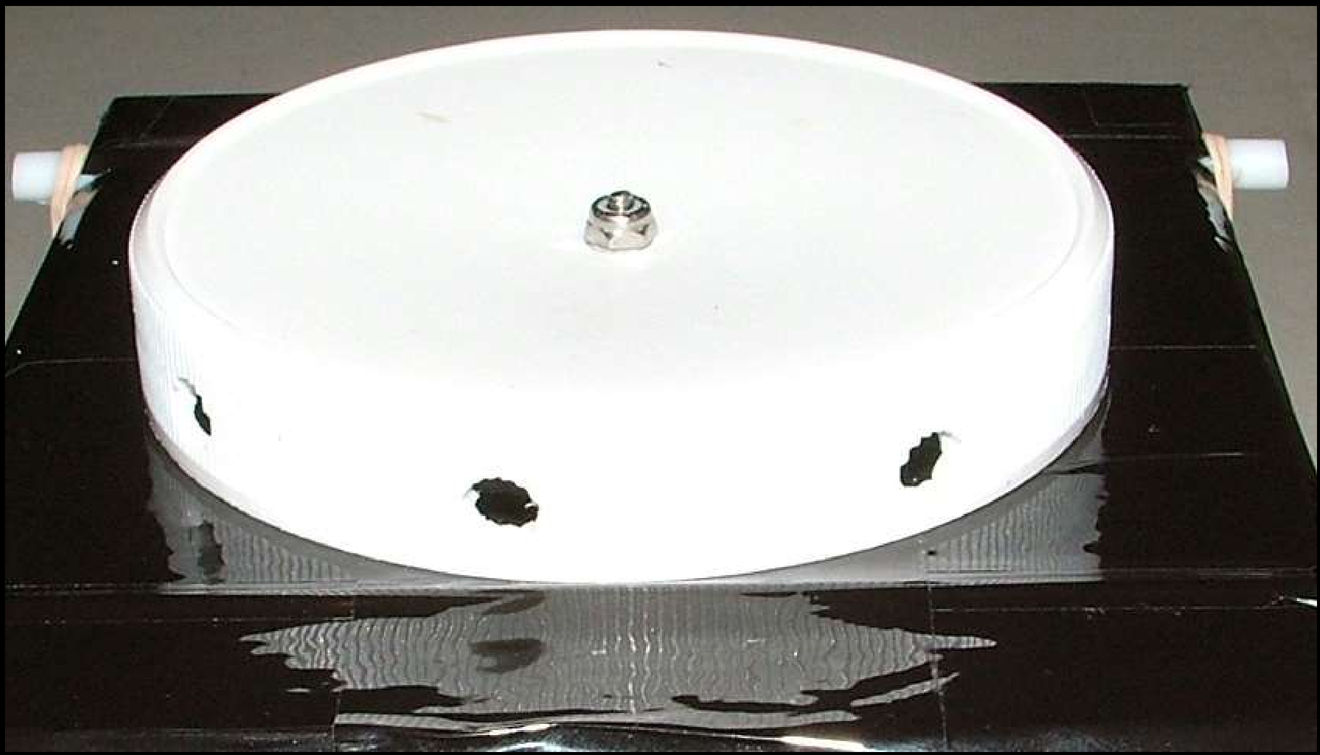


Colored Mailing Tape

- Lighter than aluminum duct tape
- Multiple colors

Plastic Lids can Shield Sensors from Direct Sunlight

- Bolt to airframe
- Add air openings



Cut Open Tubing

- Cutting away the tape covering tubes makes it easier to pass the tether though the tube

Hand Warmer as a Heat Source

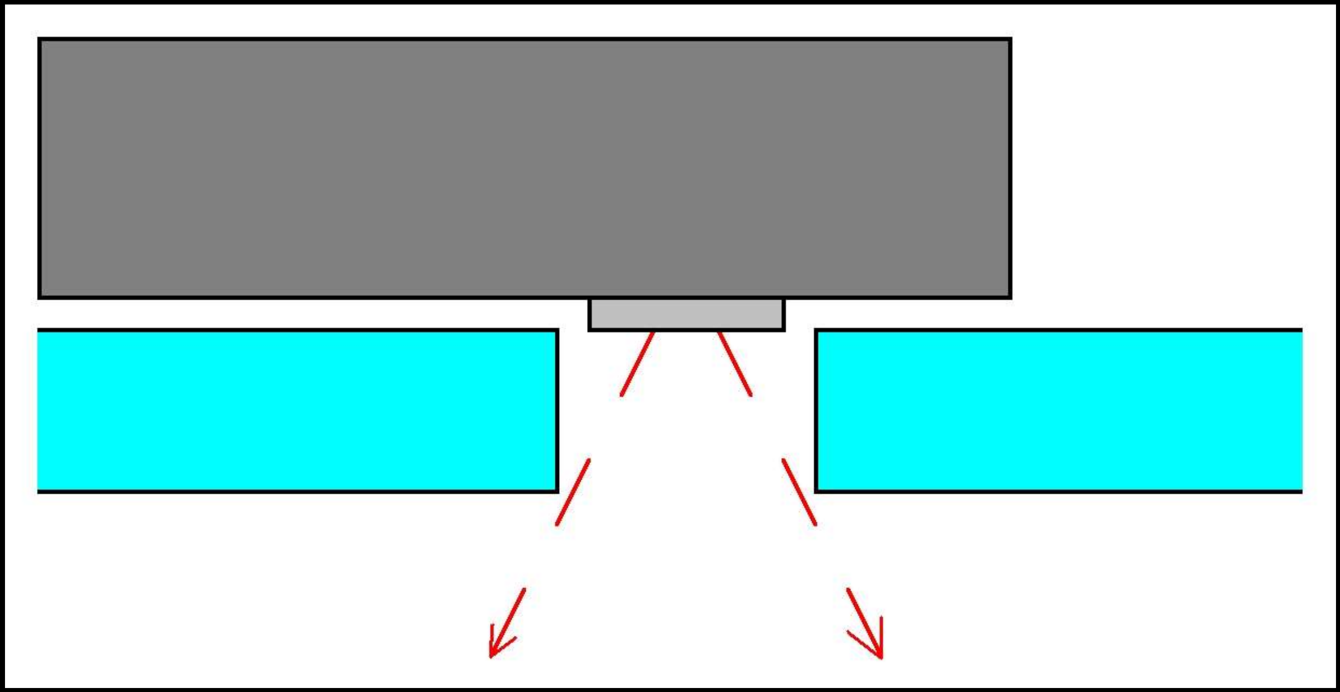
- Design a space inside the BalloonSat for a hand warmer

Camera Brace

- Glue a Styrofoam strip to the airframe and against the edge of the camera for bracing

Camera Lens Opening

- Make holes larger than lens to accommodate the camera's angle of view
- Make opening for light meter (if necessary)



Darken Camera Openings

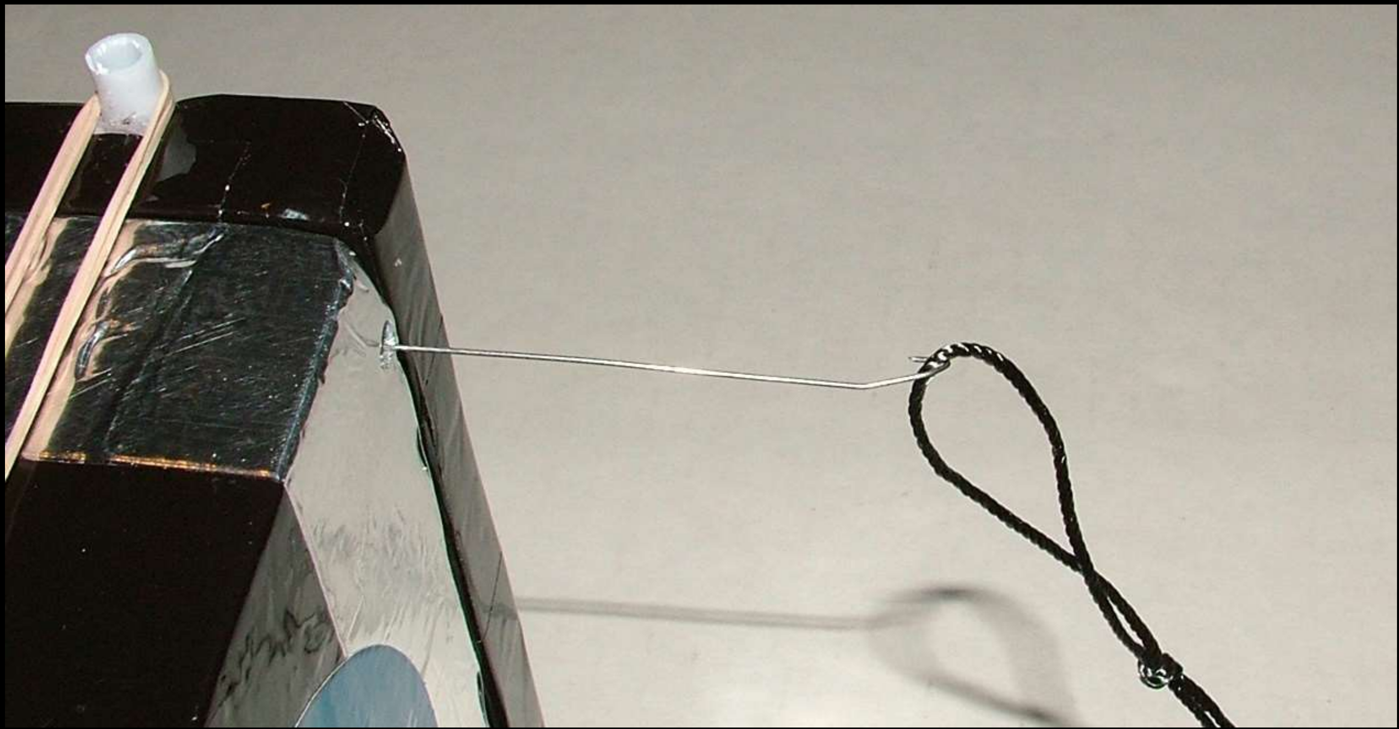
- May reduce glare

Testing

- Weight Test
- Shake Test
- Drop Test
- Cold Test
- Function Test

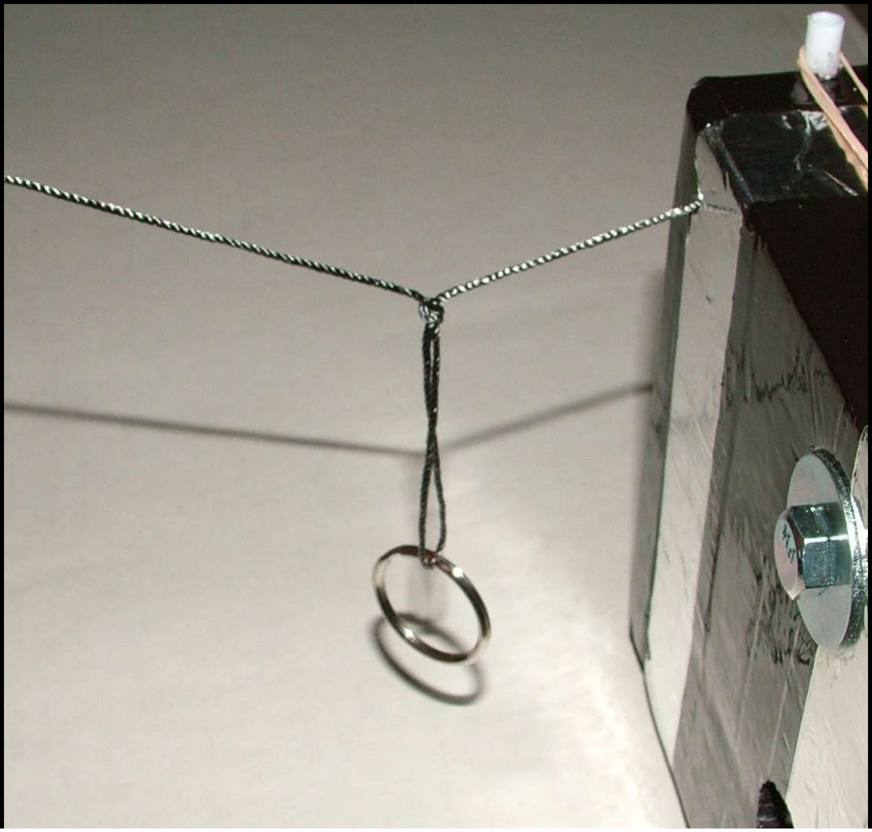
Tethering BalloonSats

- Use wire hook to pull tether through tube



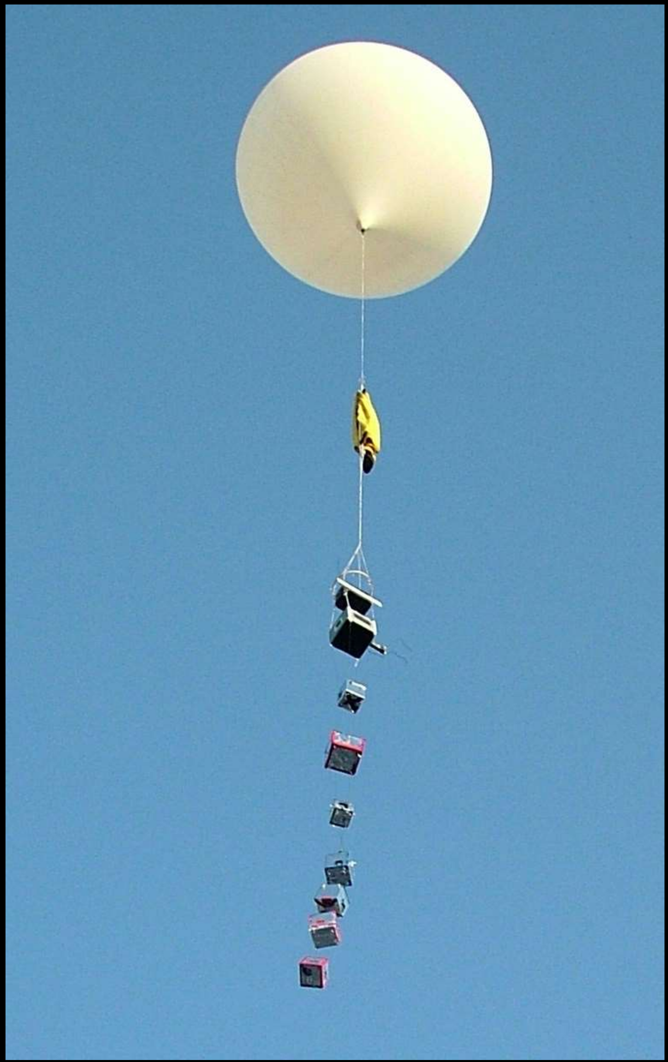
Tethering BalloonSats

- Use split rings to prevent tether from pulling out



Tethered BalloonSats

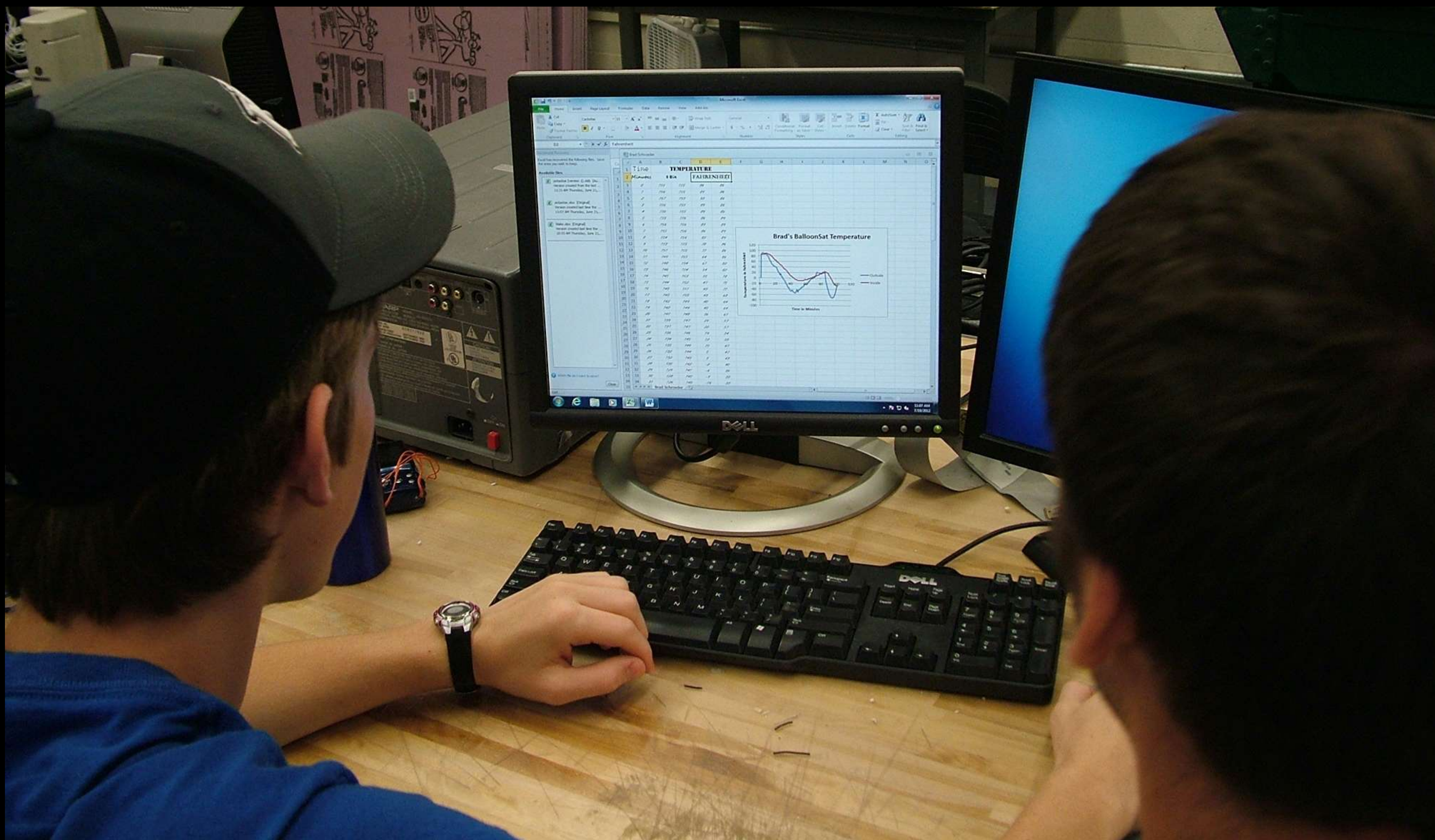
The Mission Begins



Recovery

- The mission's not over yet

Data Analysis



BalloonSat Testing

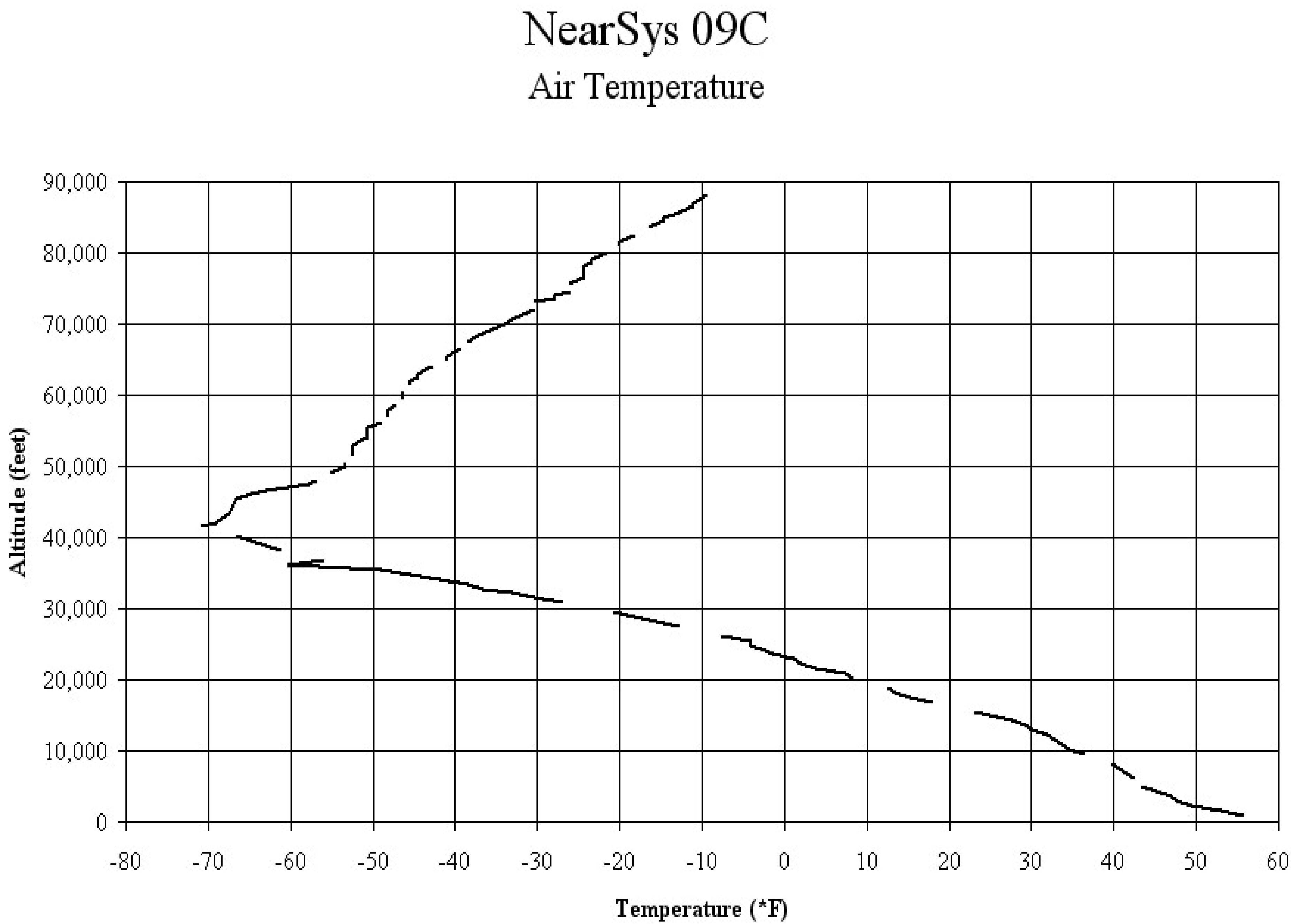
Verifying BalloonSats will function properly during a near space mission

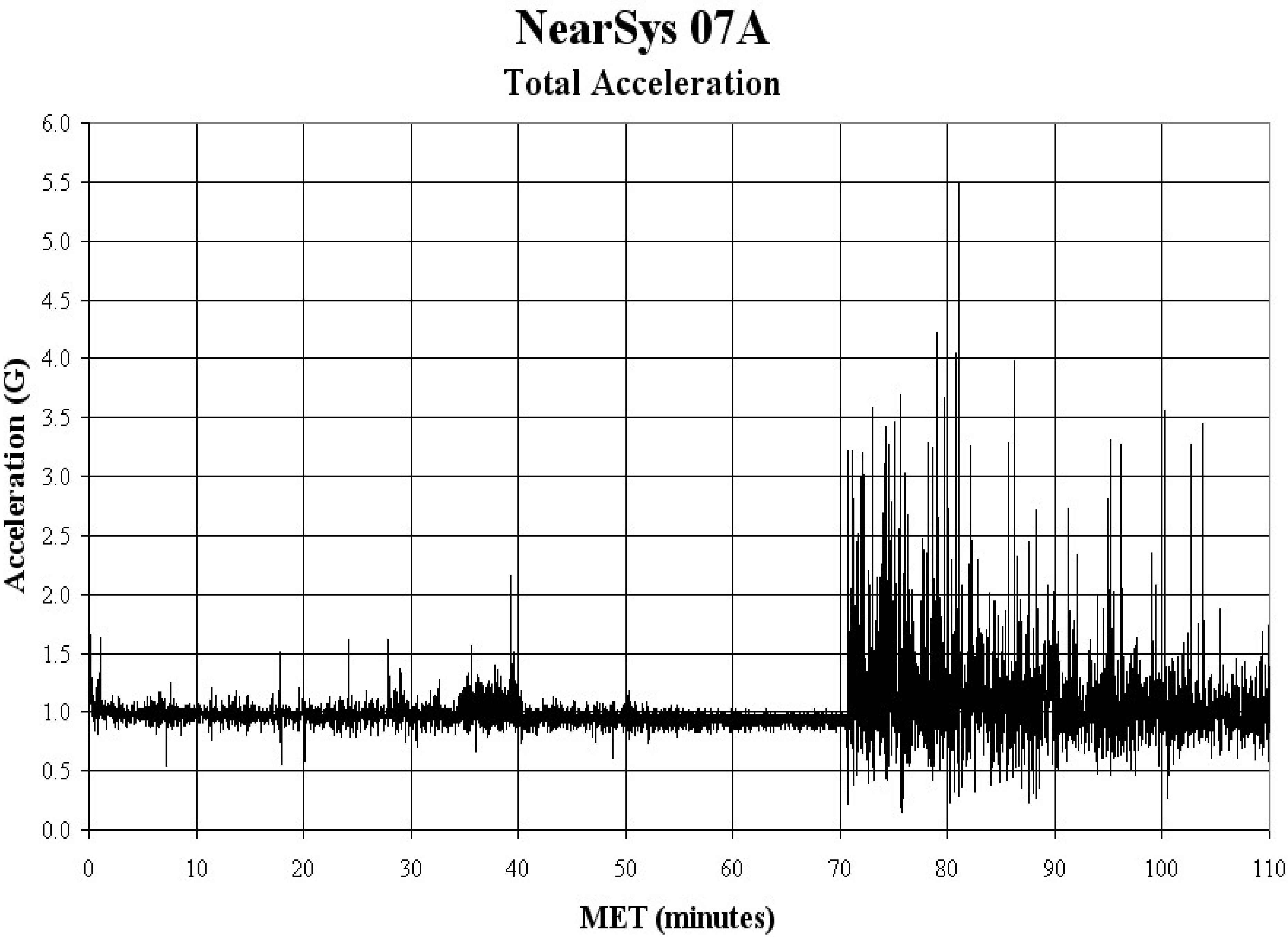
L. Paul Verhage

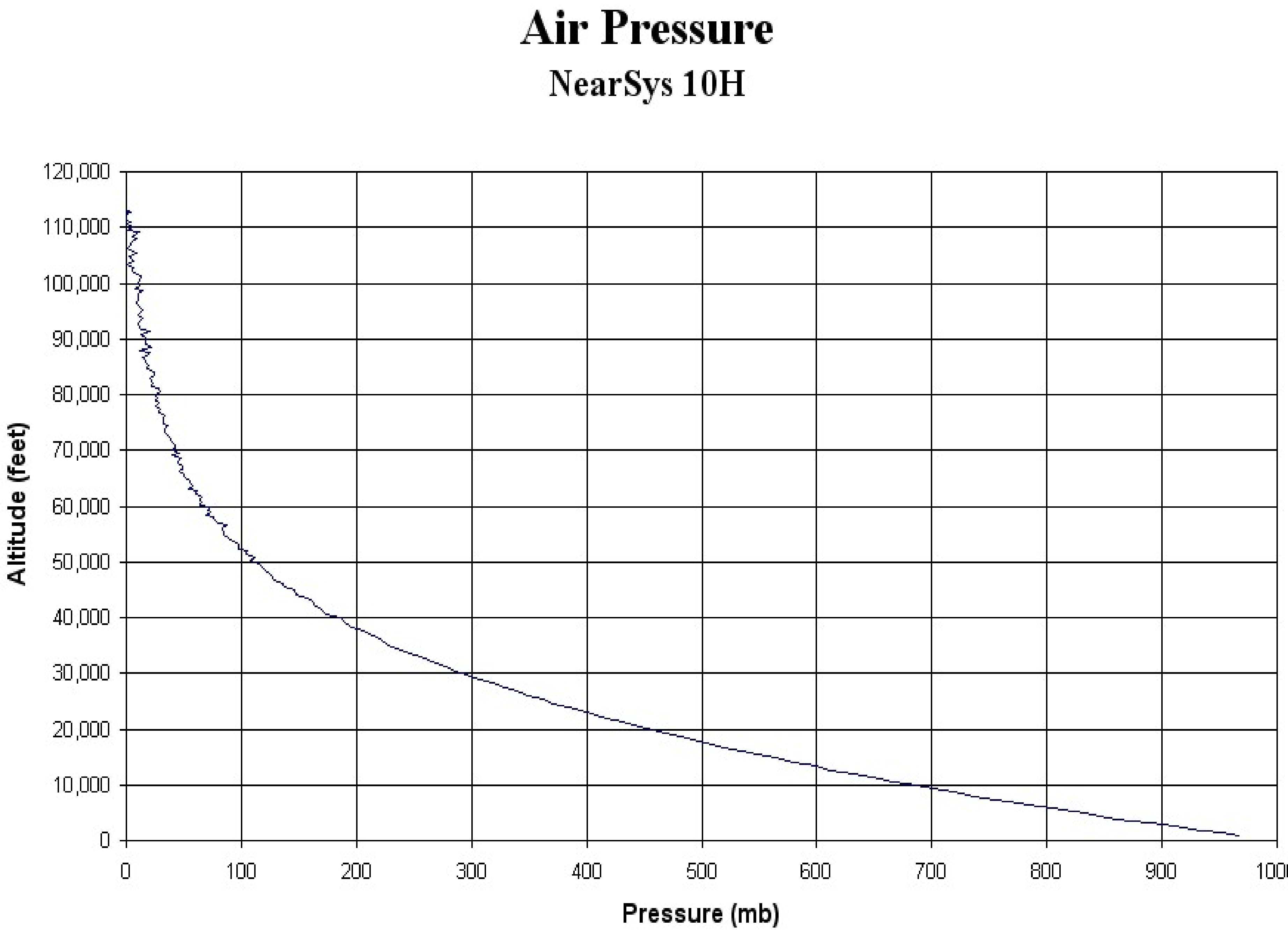
8 July 2013

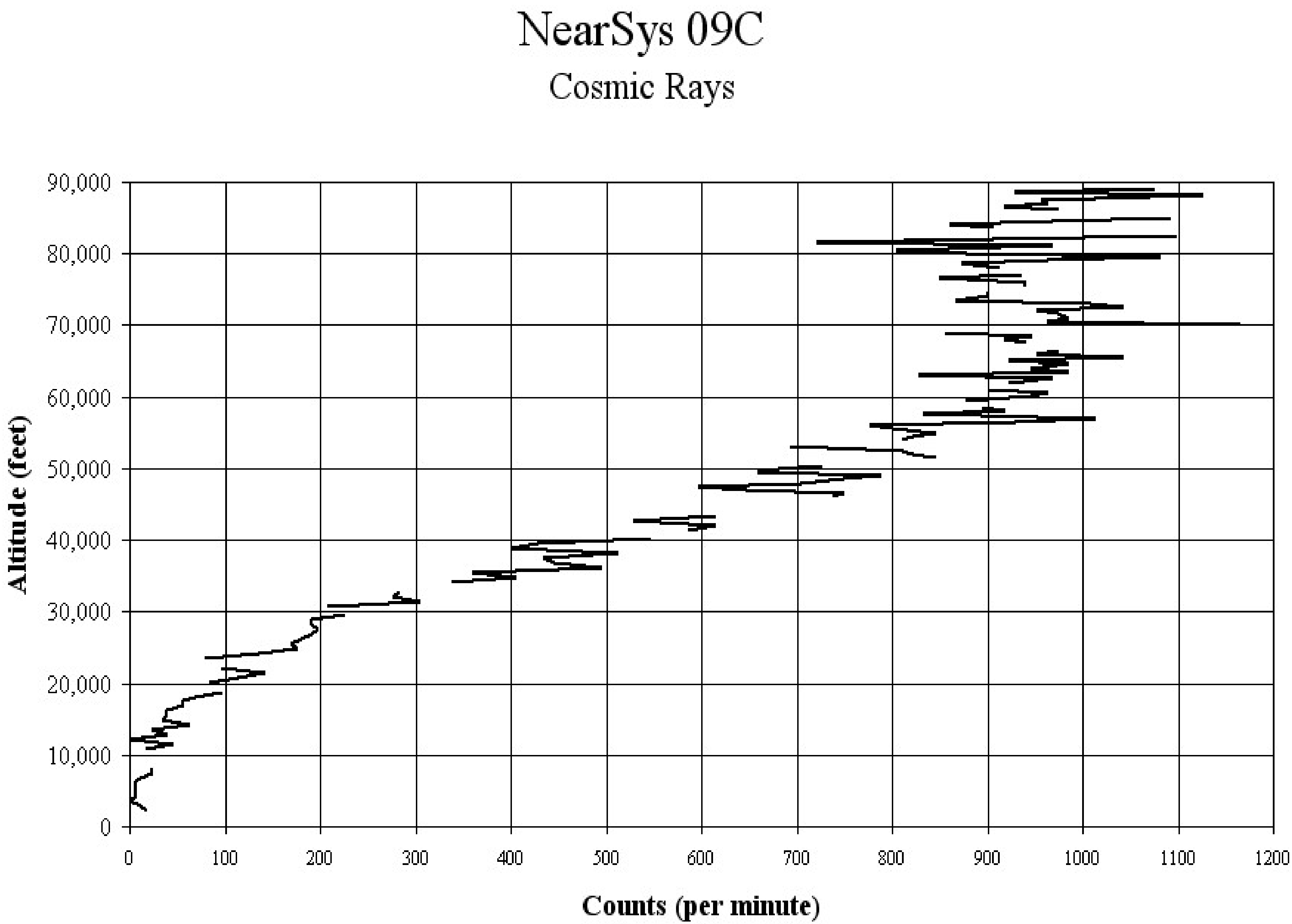
Near Space is a Hostile Environment

- Intense Cold
- Extreme Shaking
- High Vacuum
- Increased Radiation


NearSys 09C
Air Temperature
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Altitude (feet)
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
Temperature (*F)


NearSys 07A
Total Acceleration
Acceleration (G)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
90
100
110
MET (minutes)


Air Pressure
NearSys 10H
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Altitude (feet)
0
100
200
300
400
500
600
700
800
900
1000
Pressure (mb)



NearSys 09C
Cosmic Rays
Altitude (feet)
Counts (per minute)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
0
100
200
300
400
500
600
700
800
900
1000
1100
1200

Recommended Tests

- Weight Test
- Function Test
- Shake Test
- Cold Test
- Drop Test

Weight Test

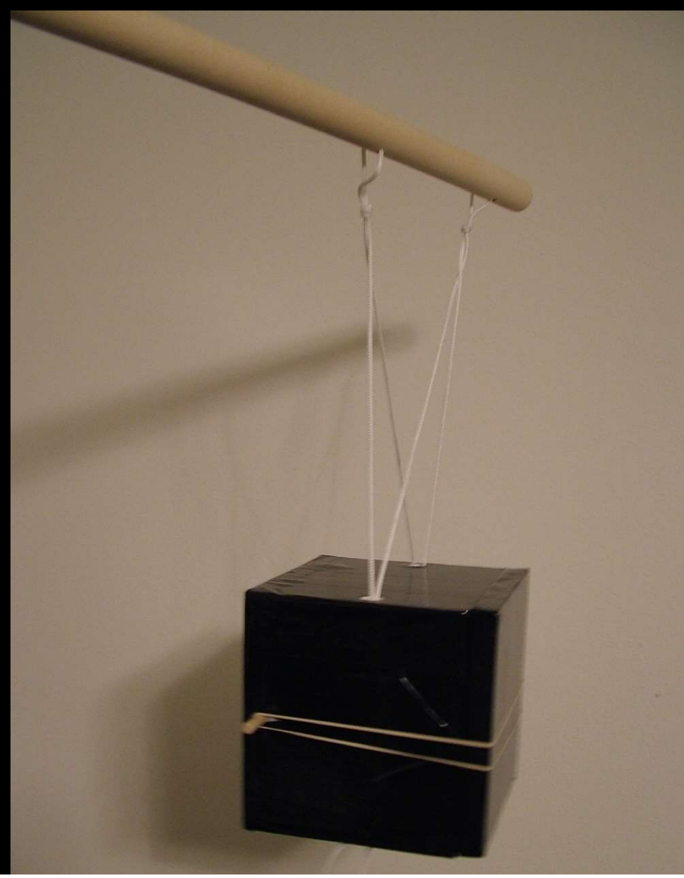
- Is the BalloonSat within weight limits

Function Test

- Does the BalloonSat start easily and does it collect data as designed

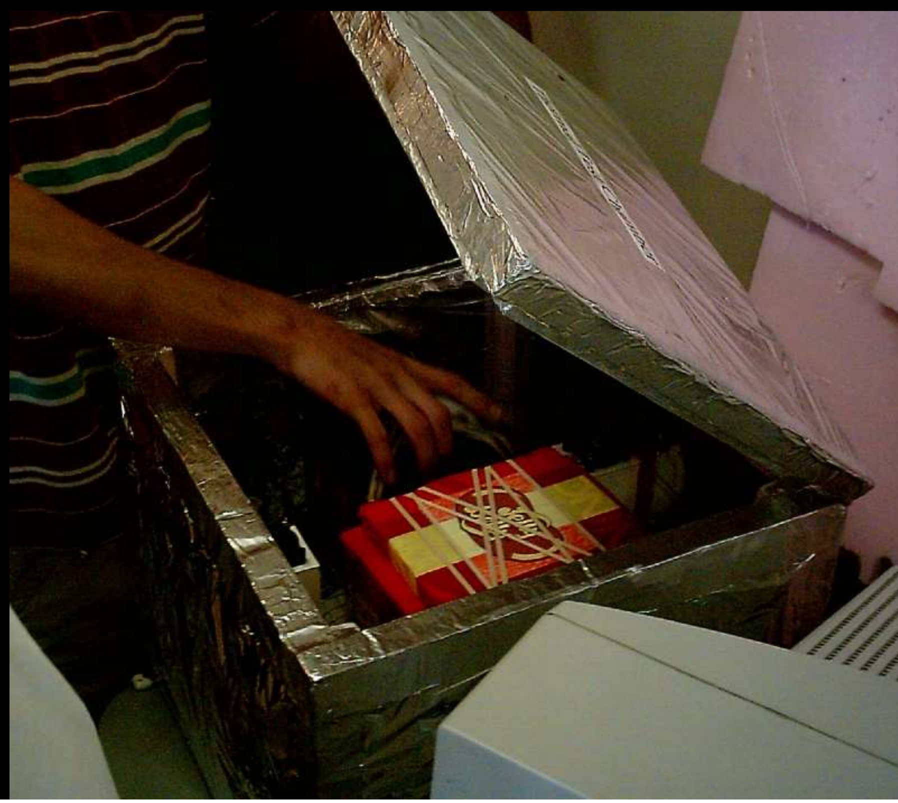
Shake Test

- Does the BalloonSat hold together during shaking



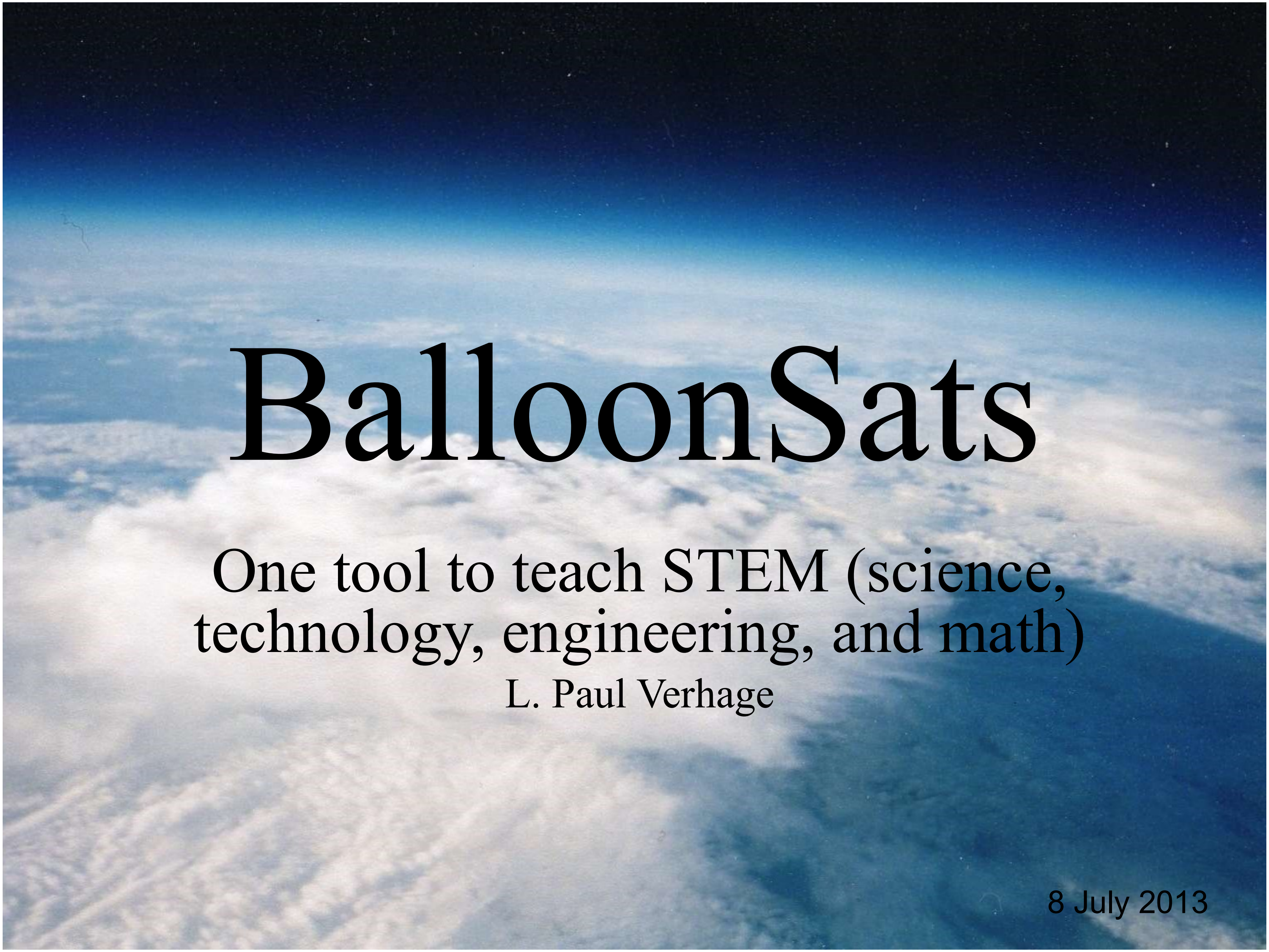
Cold Test

- Does the BalloonSat continue to function when extremely cold



Drop Test

- Does the BalloonSat hold together at landing

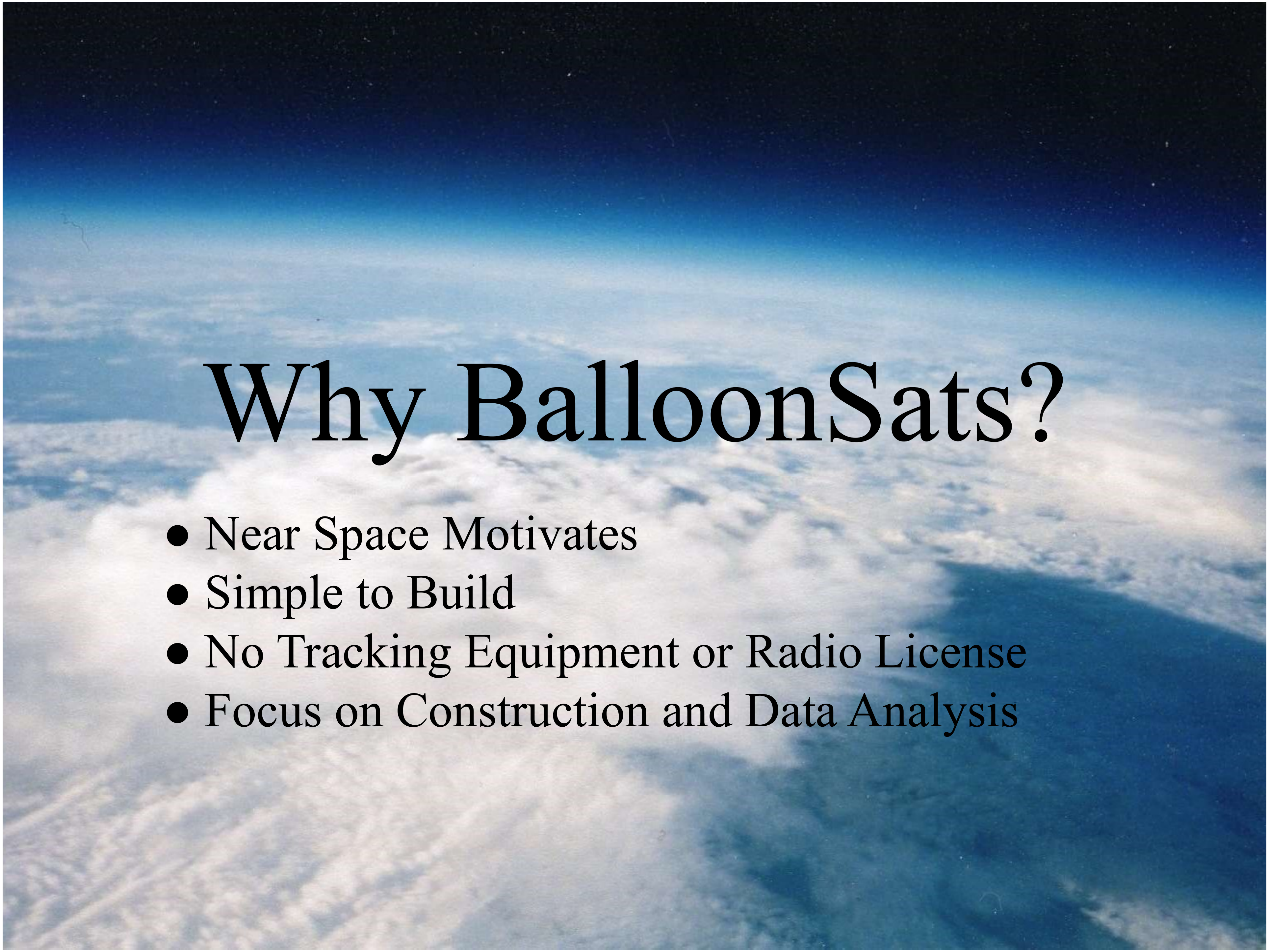


BalloonSats

One tool to teach STEM (science, technology, engineering, and math)

L. Paul Verhage

8 July 2013



Why BalloonSats?

- Near Space Motivates
- Simple to Build
- No Tracking Equipment or Radio License
- Focus on Construction and Data Analysis

A Typical BalloonSat

One or two experiments

Easy integration

Simple to program

BalloonSat Construction

Workshop

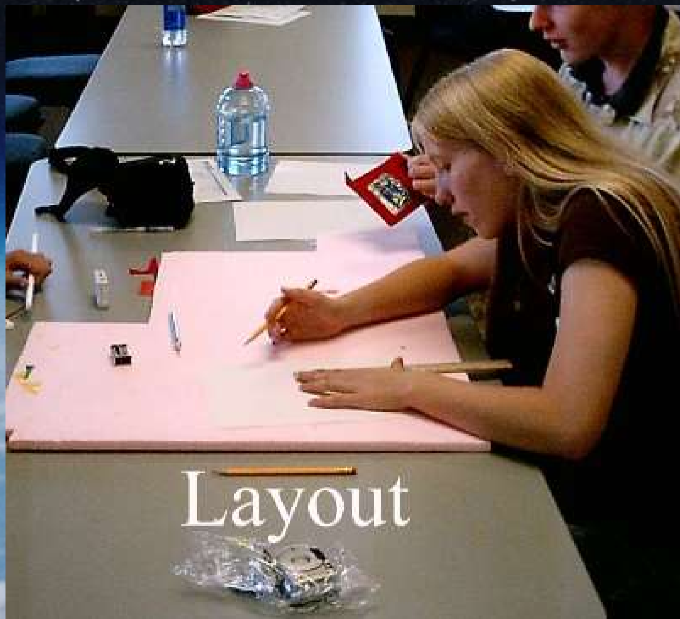
Teams of three or four

Two days/Four hours

Classroom

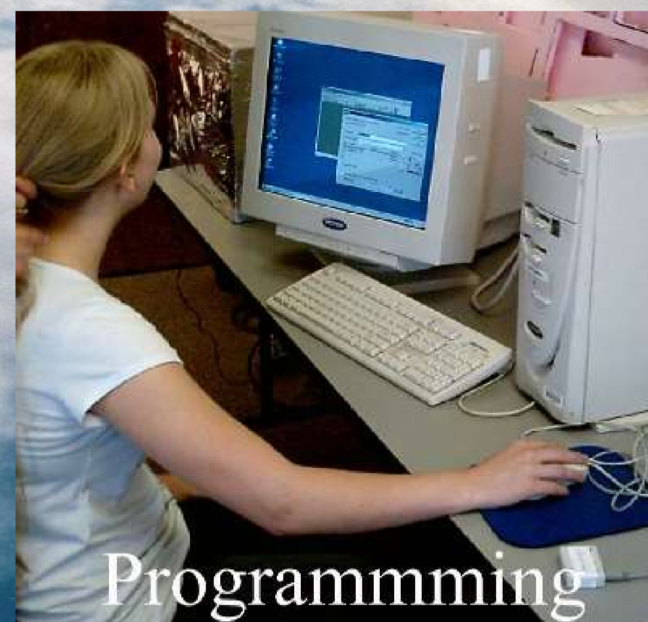
Teams of three or four

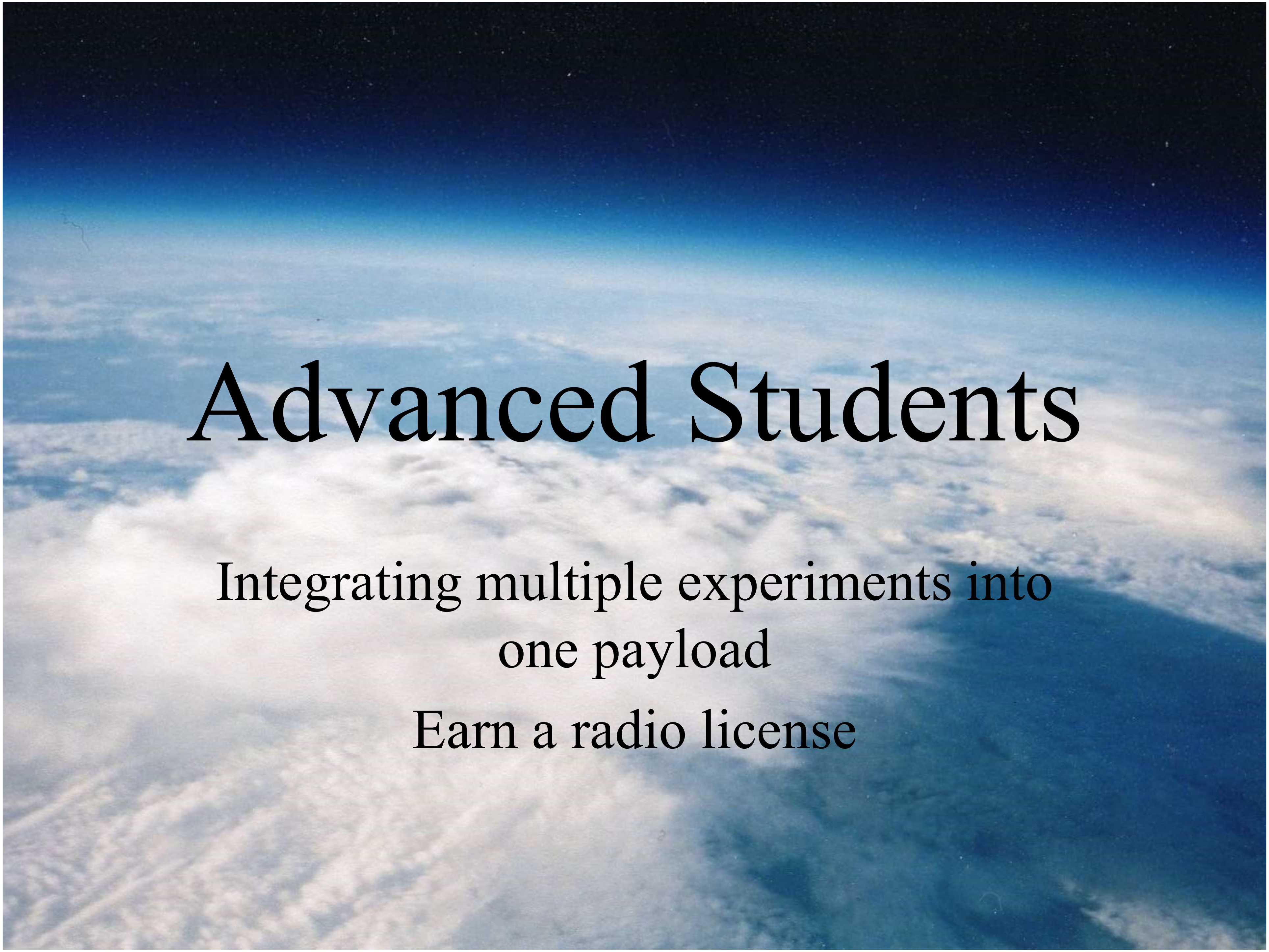
Two weeks/1 class period


Layout


Assembly

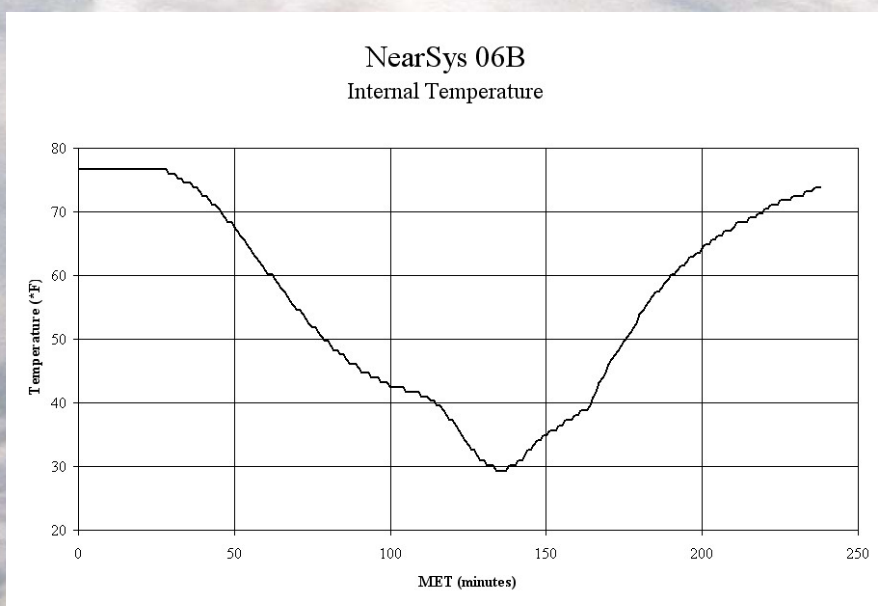

Testing


Programmming

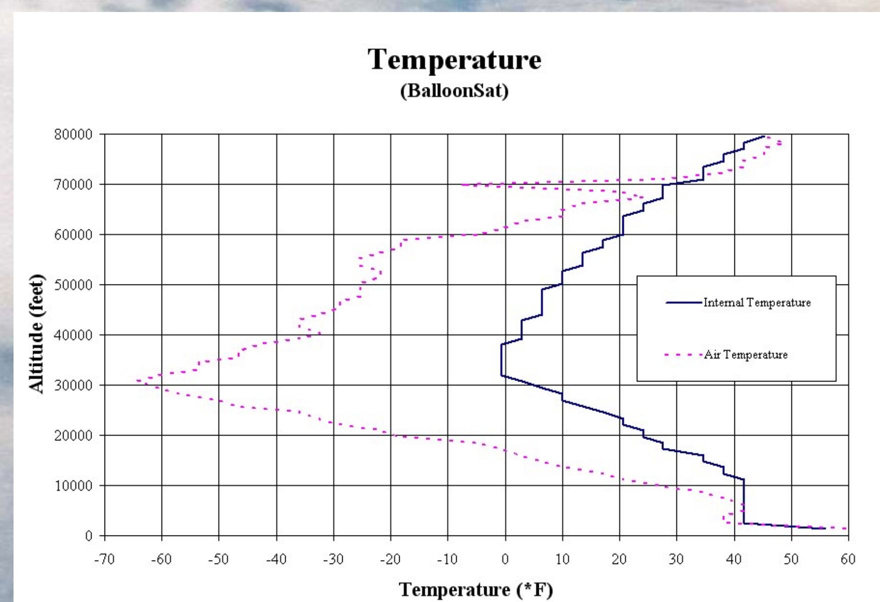

Advanced Students
Integrating multiple experiments into one payload
Earn a radio license

Student Data

Without APRS



With APRS




Potential Problems
Weather
Hot and Sharp Tools
Wrong Audience
Work Schedules
Liability


Marines


Umm, I wonder….
NearSys@gmail.com

Factors Controlling a Near Space Flight

L. Paul Verhage

10 June 2014

Five Factors

- Lift
- Weight/Drag
- Maximum Balloon Volume
- Wind Speed
- Wind Direction

Lift and Weight

- Lift and weight/drag act in opposite directions
- Weight and drag resists the ascent of the balloon
- The force of drag depends on how fast the balloon moves
- Air density and balloon size also affect the amount of drag (Hank's Knee)
- Lift, weight, and drag govern the ascent rate of the balloon

Maximum Balloon Volume

- Balloon volume doubles every 18,000 feet
- Initial fill volume governs the amount of available expansion
- Same size balloons display some variability

Wind Speed and Direction

- Balloons are captive of the wind
- Wind speed and direction changes as altitude changes

- Launching inside a high pressure system
- Stratospheric turn around
- Jet stream

Three Useful Online Applications

- LiftWin
- BallTrak
- UKHAS Flight Prediction

LiftWin

- Calculates the lifting behavior of a weather balloon
- Ascent Rate
- Burst Altitude

BallTrak and UKHAS

- Predicts flight path of a balloon flight
- Inputs: Ascent rate and balloon burst altitude
- Output: Flight path plotted on Google Maps

Predicting Near Space Flights

L. Paul Verhage

28 December 2014

General Rules

- High pressure systems generally means short flight paths
- A jet stream aloft increases the flight path distance
- An additional pound or two of lift creates a shorter mission and flight path without decreasing maximum altitude by a measurable amount

CUSF Flight Predictor

Inputs

- Launch site (latitude, longitude, altitude)
- Launch Date/Time
- Ascent rate (feet per minute)
- Burst Altitude (feet)

Output

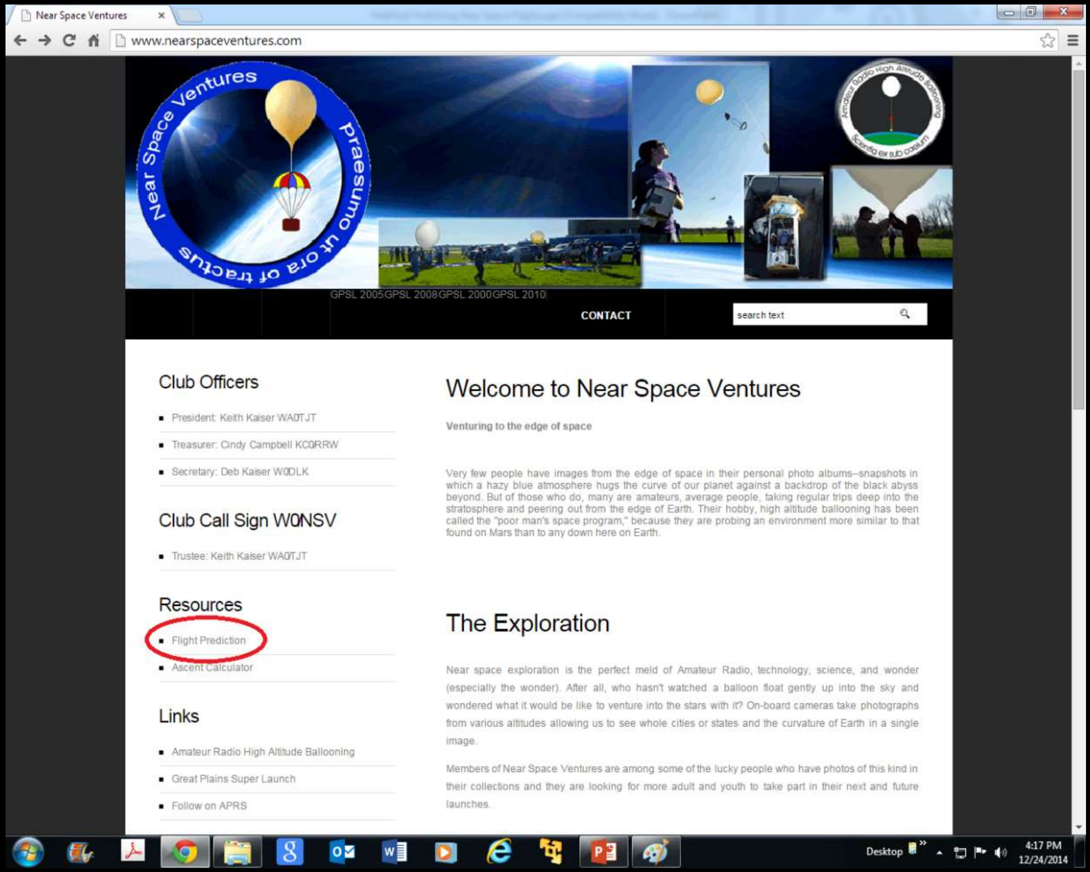
- Flight path on Google Maps

Items to Look For

- Turn around
- Locations beneath descent path

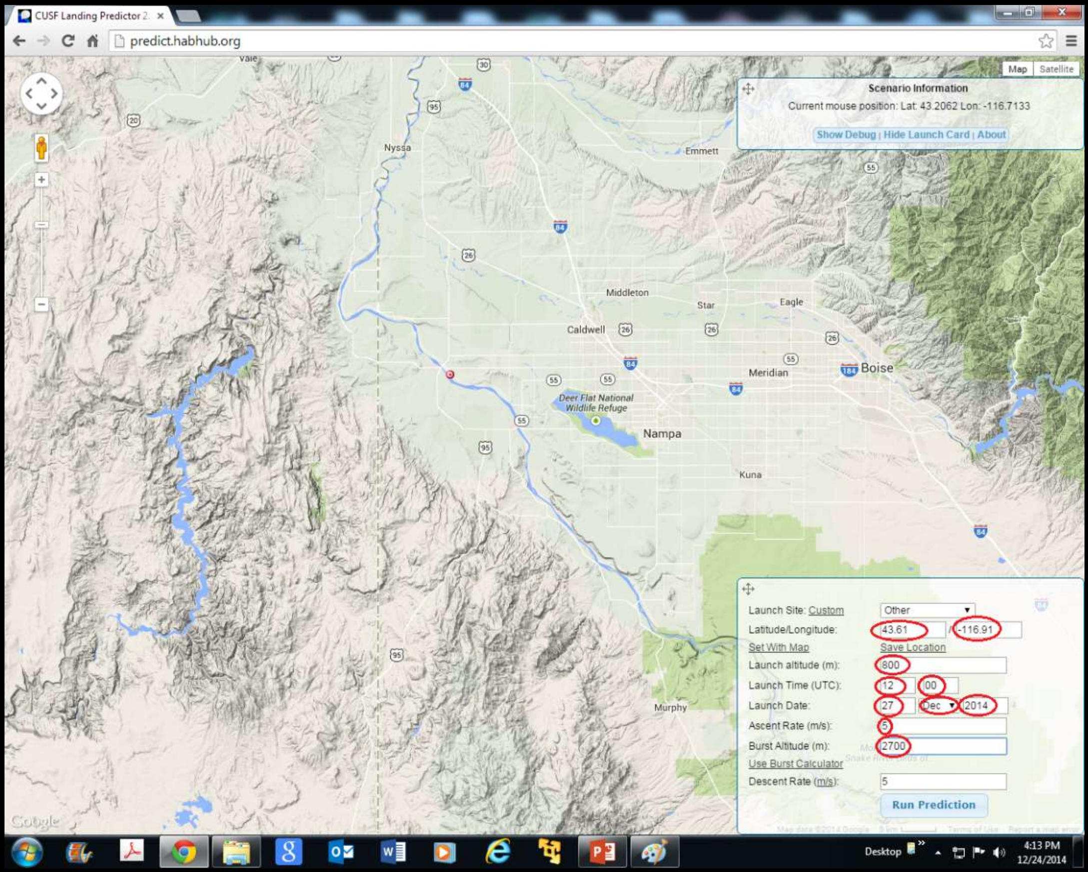
The Near Space Ventures Website

- www.nearspaceventures.com



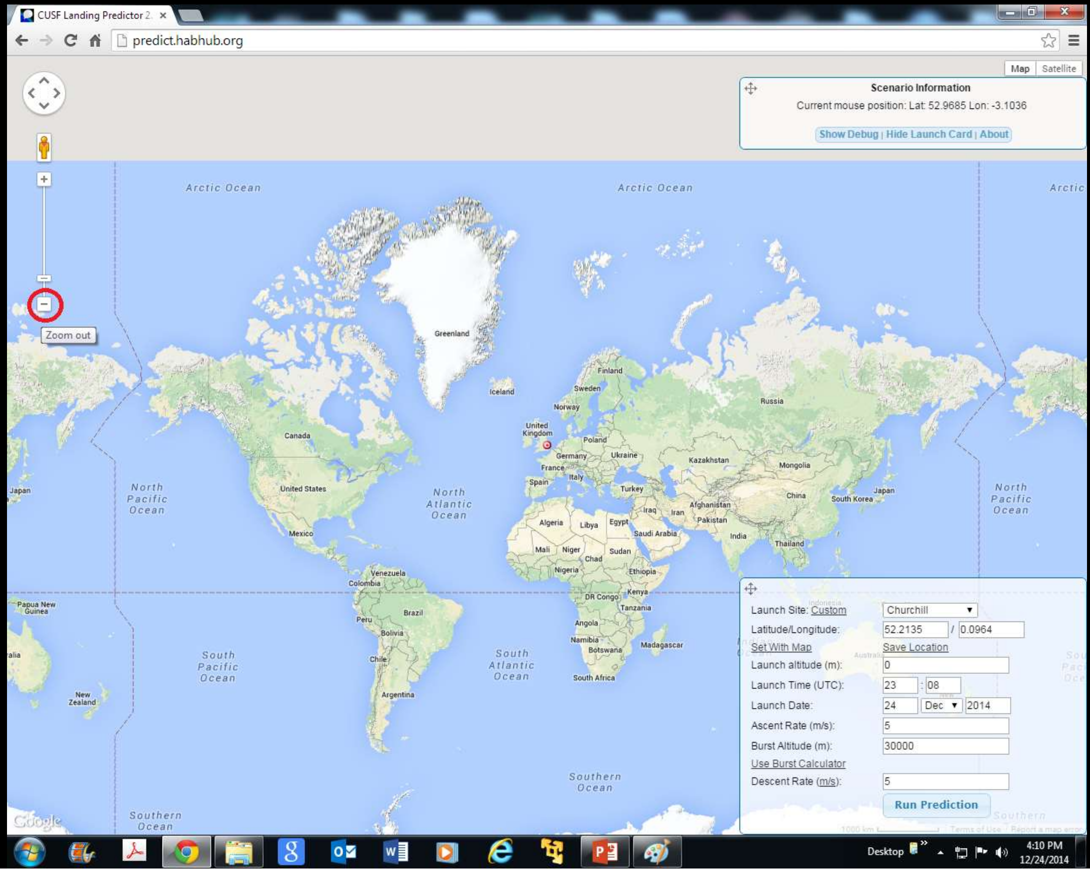
Online Near Space Flight Prediction

- Enter data into all of the fields



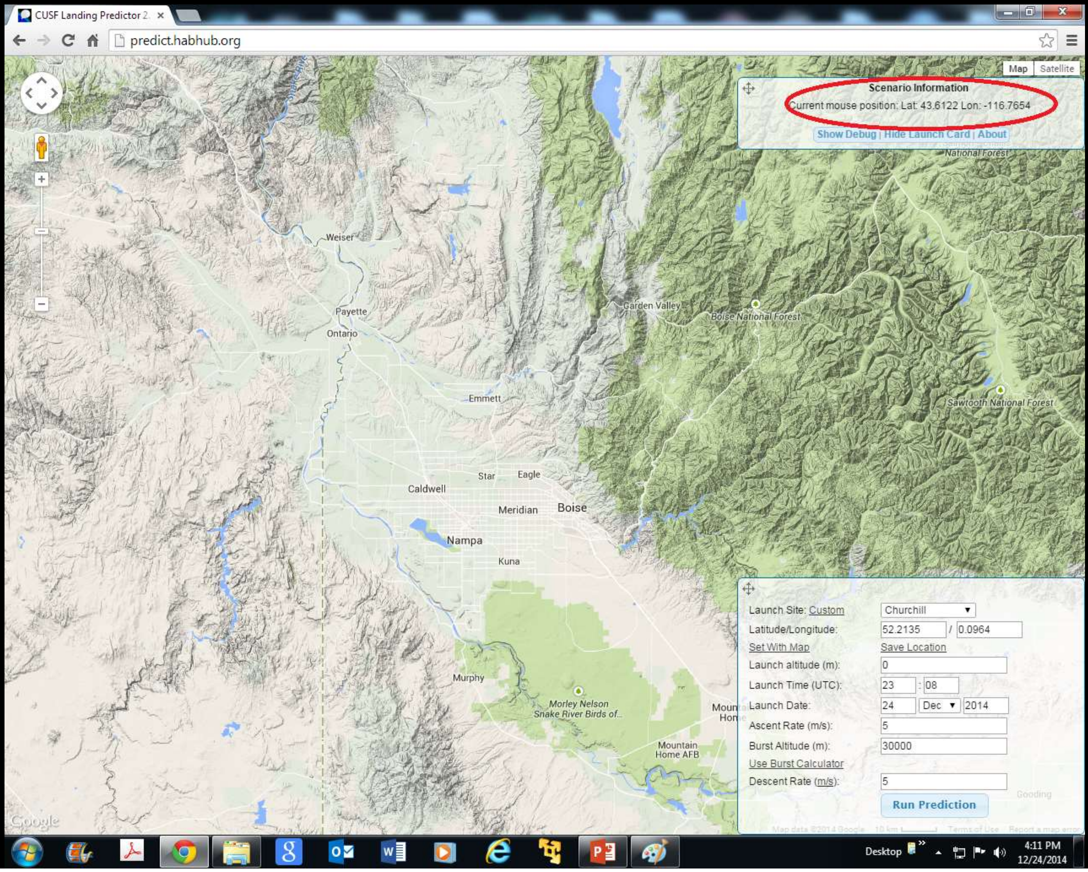
If You Don't Know Your Latitude and Longitude

- Zoom out until you can find your location on Earth



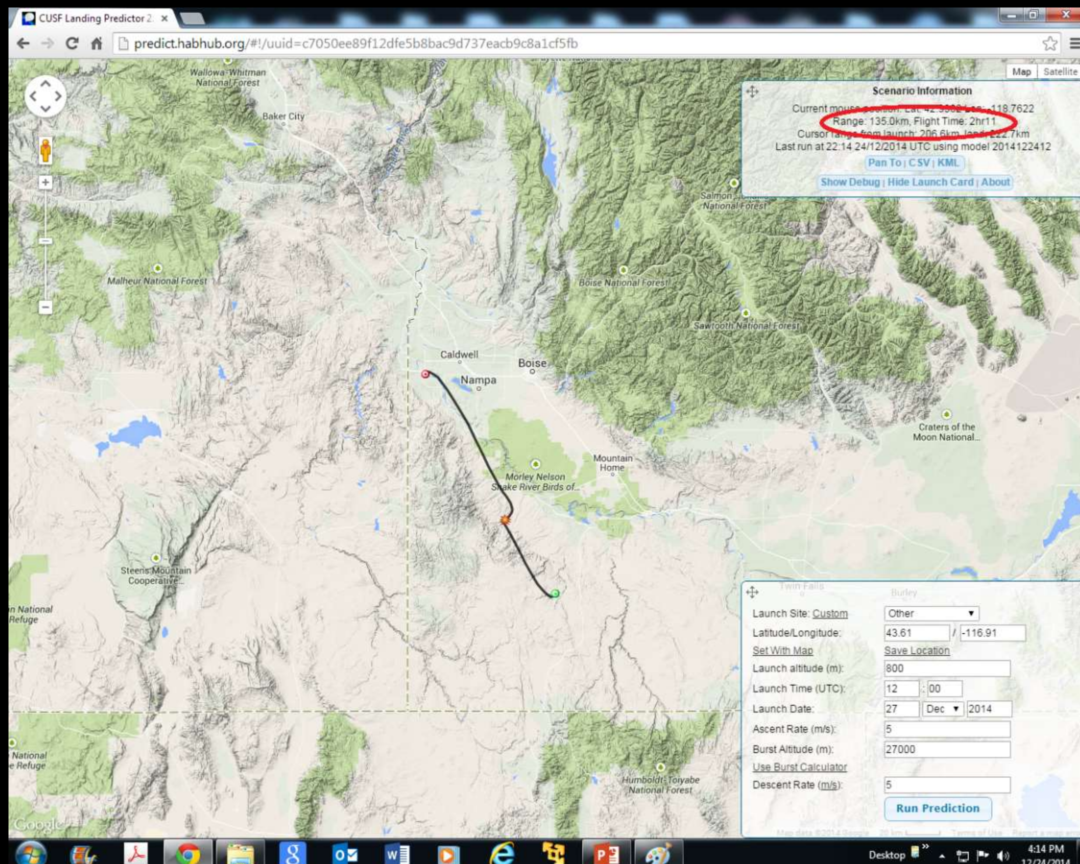
If You Don’t Know Your Latitude and Longitude

- The coordinates are displayed as you move around the mouse/hand



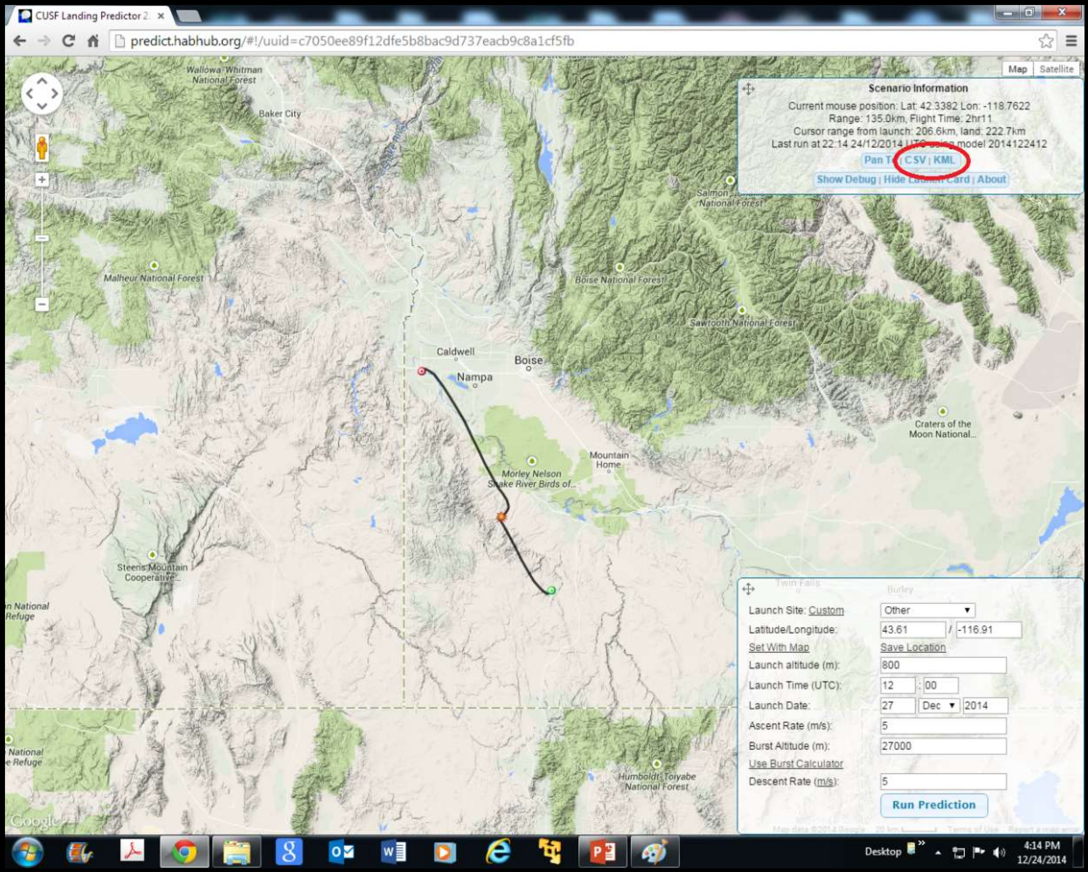
Prediction Output

Check the Range and Time



Prediction Output

- You can also get CSV and KML files of the flight



Making Better Predictions

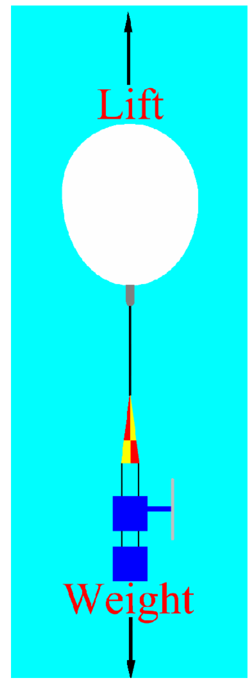
- Run predictions daily for several days
- Create a recovery ellipse
- Rerun predictions with different ascent rates, descent rates, and burst altitudes
- Rerun predictions using winds nearest launch site and nearest recovery zone

Launch Time!

How Much Gas do I Need to Launch a Near Spacecraft?

In order for a near spacecraft to lift off, its balloon (launch vehicle) must displace a greater weight of air than the near spacecraft weighs. Generating more lift than weight is called **buoyancy**. We can calculate the buoyancy of a balloon by subtracting the density of the lifting gas from the density of the atmosphere and by multiplying by the volume of the balloon (the volume of the balloon equals the amount of gas used to fill it).

Density of the Atmosphere



Earth's atmosphere consists of 78% nitrogen (N_2), 21% oxygen (O_2), and 1% argon (Ar). All other gases appear in trace amounts and do not significantly affect the density of the atmosphere. Chemists use the term **mole** to refer to a collection of **6.022×10^{23}** objects, including atoms and molecules. This is no different than using the term dozen to refer to a collection of 12 objects. It's just a mole is more convenient when referring to a collection of very small atoms and molecules. At standard temperature and pressure (**STP**), one mole of every gas occupies a volume of **22.4 liters**. STP is the condition of 0^o C and 1 atmosphere of pressure. Even if you won't launch a balloon at STP, knowing the volume and mass of a mole of gas at STP is important to determining the buoyancy of a balloon. This is because both the lifting gas (using hydrogen or helium) and the atmosphere change in the same ways as conditions deviate form STP. Therefore, once you know the buoyancy of a balloon at STP, you know the buoyancy of the balloon at other temperatures and pressures.

Look at a periodic table of the elements to determine the mass (which we'll treat as weight in this case) of a mole of atoms. Nitrogen has a mass of 14 grams per mole. However, nitrogen is a diatomic gas and appears as N_2 in the atmosphere. This means a mole of nitrogen gas has a weight of 28 grams. Since oxygen exists as O_2 in our atmosphere, one mole of oxygen gas has a weight of 32 grams. Argon is a noble gas and therefore unreactive. This means the weight of one mole of argon is 40 grams.

Combining the weights and abundances of the three major gases in Earth's atmosphere and dividing by their volume allows us to calculate the density of the atmosphere.

Density = [(mass of N_2 * abundance N_2) + (mass of O_2 * abundance O_2) + (mass of Ar * abundance Ar)] / 22.4 liters

Density = [(28g * 0.78) + (32g * .21) + (40g * 0.01)]/22.4 liters

Density = [28.6 g]/22.4 liters

Density = 1.28 g/L

Now lets convert this to pounds per cubic foot since these are the units we're most familiar with and they're the ones we'll be measuring.

Density of Earths' atmosphere at STP = 1.28 g/L * (1 lb / 454g) * (28.3 liters / 1 cubic foot) or 0.08 pounds / cubic foot.

Buoyancy of Hydrogen and Helium
Hydrogen gas has a weight of 2 grams per mole and therefore a density of 2 grams / 22.4 liters. This is 0.006 pounds / cubic foot

Helium has a weight of 4 grams per mole and therefore a density of 4 grams / 22.4 liters. This is 0.012 pounds / cubic foot.

The buoyancy of hydrogen = (0.08 pounds / cubic foot) – (0.006 pounds / cubic foot) = 0.074 pounds / cubic foot.

The buoyancy of helium = (0.08 pounds / cubic foot) – (0.012 pounds / cubic foot) = 0.068 pounds / cubic foot.

Therefore, we have calculated that our near spacecraft requires one cubic foot of hydrogen for every 0.074 pounds of weight or one cubic foot of helium for every 0.068 pounds of weight.

Weight of a Near Spacecraft
One thing people forget to add to their calculation of lifting gas volume is the weight of the balloon. The lifting gas must be able to lift the balloon before it can even begin to lift the parachute, tracking modules, or BalloonSats. So let's total up the maximum weight we're allow to launch under the rules of **FAR 101**.

  1200 gram balloon (a typical balloon) or 2.6 pounds
\+ 1 pound parachute
<u>+ 12 pounds of payload weight</u>
= 15.6 pounds

Amount of Lifting Gas
Now convert 15.6 pounds into cubic feet of lifting gas.

Hydrogen: 15.6 pounds * (1 cubic foot / 0.074 pounds) = **211 cubic feet**

Helium: 15.6 pounds * (1 cubic foot / 0.068 pounds) = **229 cubic feet**

What Size of Gas Bottles does a Near Spacecraft Need?
The largest tank of hydrogen is a **K tank**, which contains 196 cubic feet of gas. This means a single K tank does not contain a sufficient volume of gas to lift the maximum weight near spacecraft. The balloon needs another 15 cubic feet just to be **neutrally buoyant**. Neutrally buoyant means the balloon has just enough gas to negate its weight.

There is no extra gas to lift the near spacecraft off the ground. The balloon needs additional gas in order to ascend.

The largest tank of helium is a **T tank**, which contains 291 cubic feet of gas. Therefore, a single T tank of helium is more than enough to launch a near spacecraft.

The more gas a balloon contains above that to be neutrally buoyant, the faster the near spacecraft will ascend. An ascent rate of 1,000 feet per minute can be achieved with roughly three extra pounds of buoyancy. The amount of buoyancy (in pounds) greater than the payload weight is called the balloon's **pounds of positive lift** (PPL). Three PPL is generated by 41 cubic feet of hydrogen or 44 cubic feet of helium.

Ascending at a rate of less than 1,000 feet per minutes is viable; however, it increases the length of the mission and therefore the greater the chase distance to the recovery zone. Using significantly less buoyancy incurs the risk of the balloon becoming neutrally buoyant some time during the ascent. This results in the near spacecraft getting lost once its batteries have discharged and the tracking system stops transmitting position reports.

Therefore, assuming a maximum weight for the near spacecraft and three PPL, you need the following amounts of hydrogen and helium.

Hydrogen: 252 cubic feet
Helium: 273 cubic feet

Therefore, a hydrogen-filled balloon requires a **K tank** (196 cubic feet) plus a **Q tank** (65 cubic feet) and a helium-filled balloon requires a **T tank** (296 cubic feet)

Calculating the Amount of Gas for any Near Spacecraft
Putting all the pieces together, we find that we can calculate the amount of gas needed for any near space mission as follows.

Hydrogen: Add the amount of PPL, the weight of the balloon, the weight of the parachute, and the weight of the modules then multiply by 13.5.

Helium: Add the amount of PPL, the weight of the balloon, the weight of the parachute, and the weight of the modules then multiply by 14.7.

We can also see that hydrogen generates [(14.7 – 13.5) / 14.7] * 100% or 8.2% more lift than helium.

Using LiftWin

L. Paul Verhage

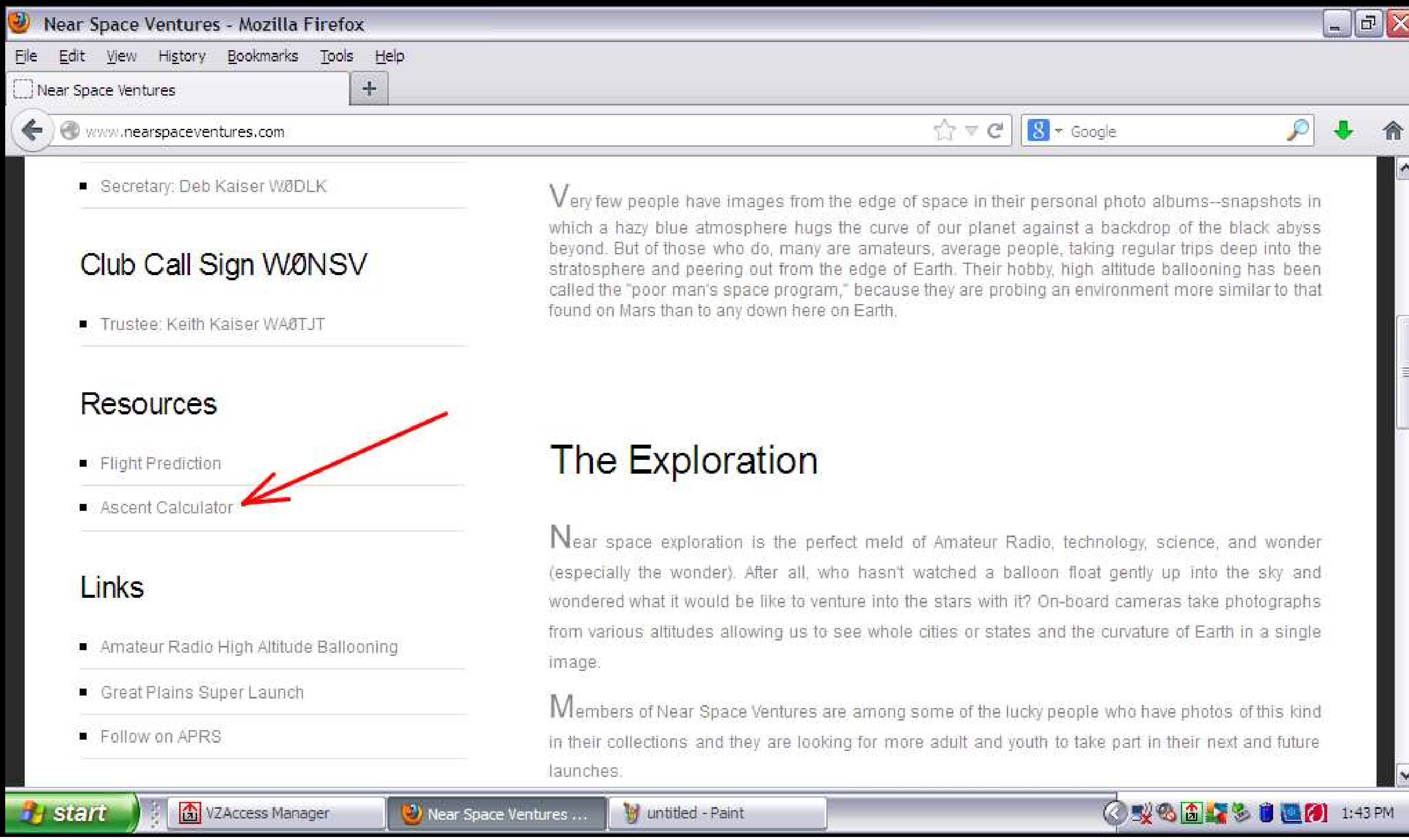
14 July 2013

Purpose

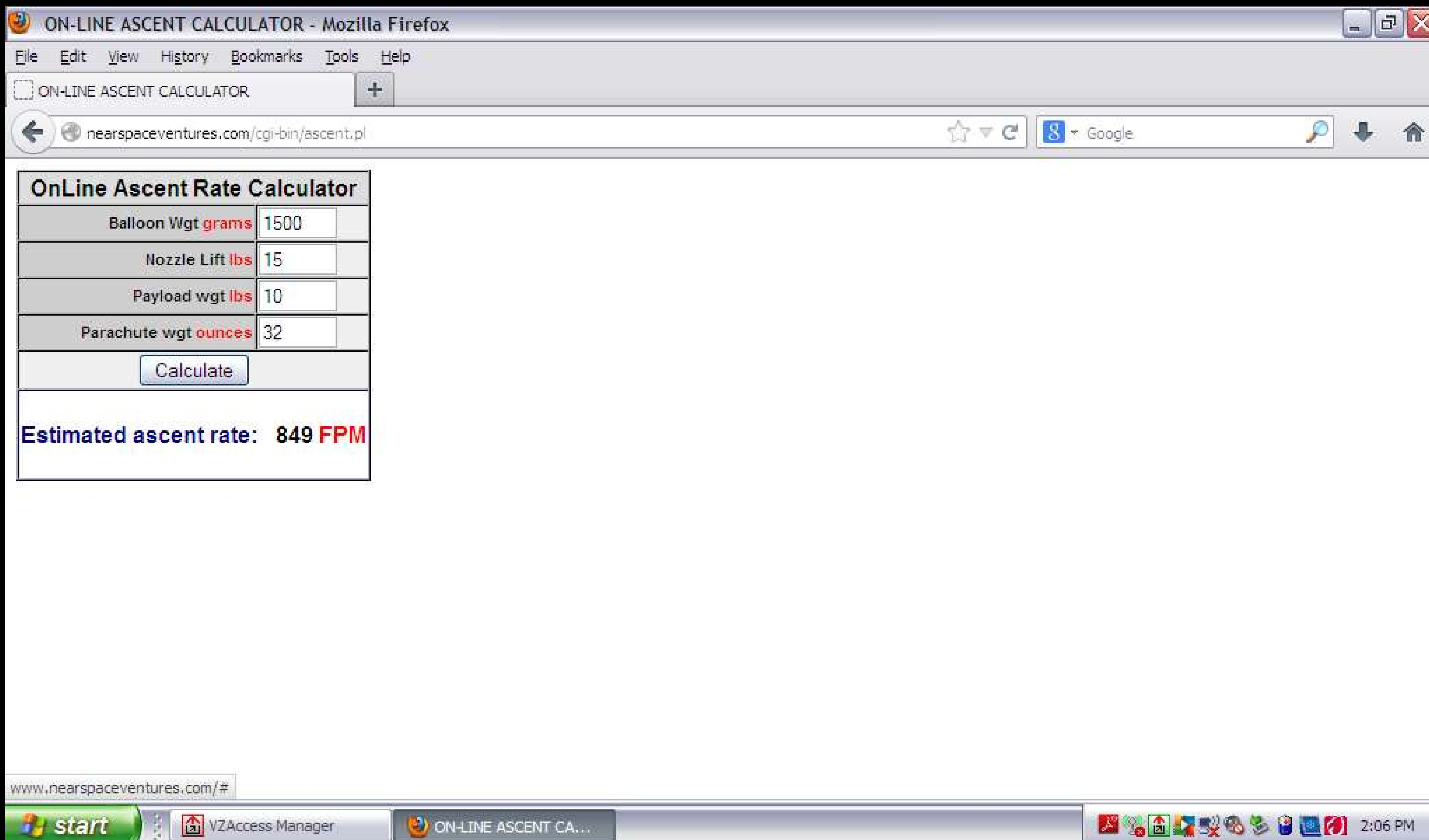
- Predicts the ascent rate of balloons
- Based on balloon size (weight), payload weight, parachute weight, and amount of nozzle lift

The Near Space Ventures Website

- www.nearspaceventures.com



LiftWin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OnLine Ascent Rate Calculator
Balloon Wgt grams 1500
Nozzle Lift lbs 15
Payload wgt lbs 10
Parachute wgt ounces 32
Calculate
Estimated ascent rate: 849 FPM
www.nearspaceventures.com/#
start
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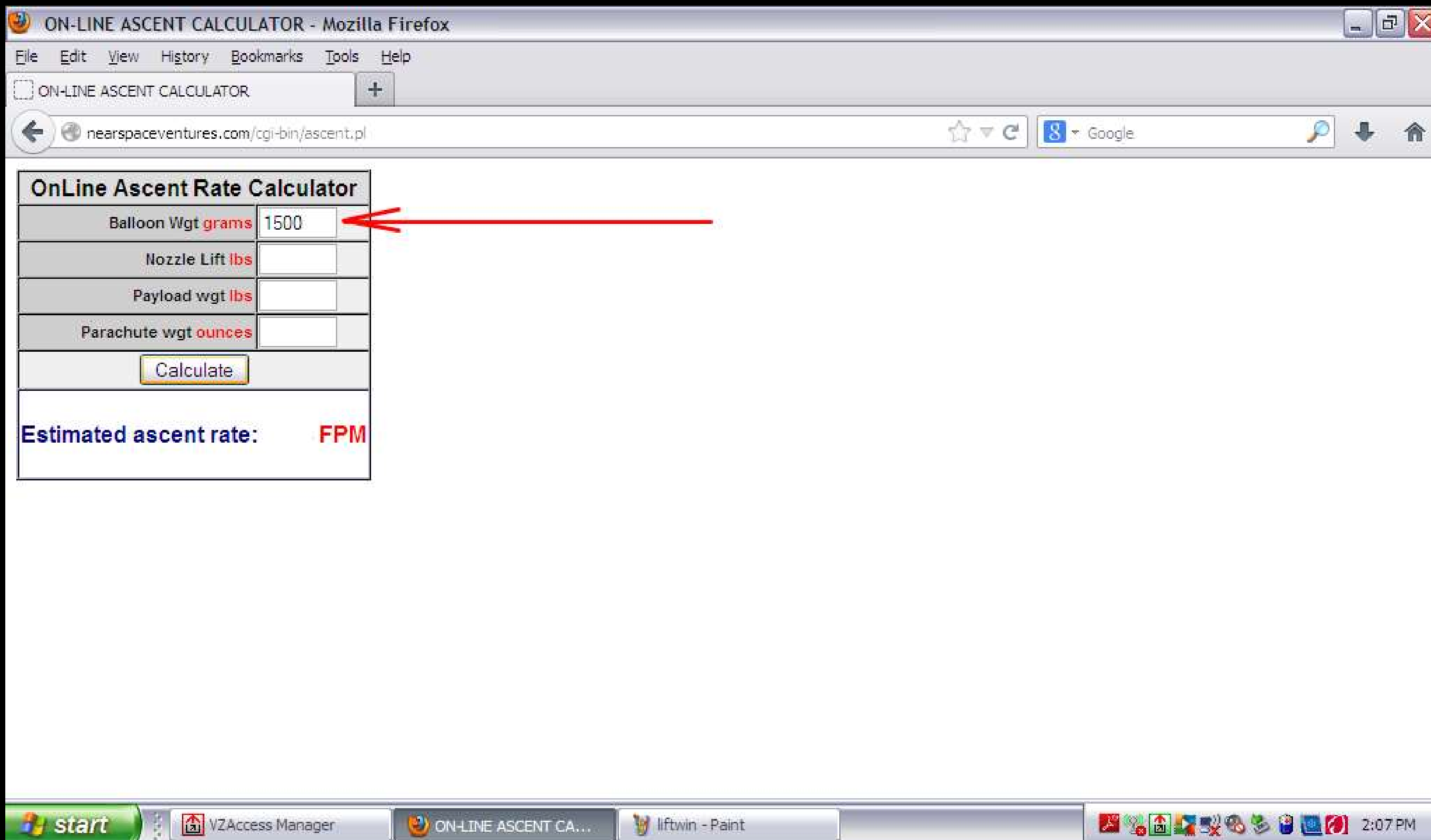
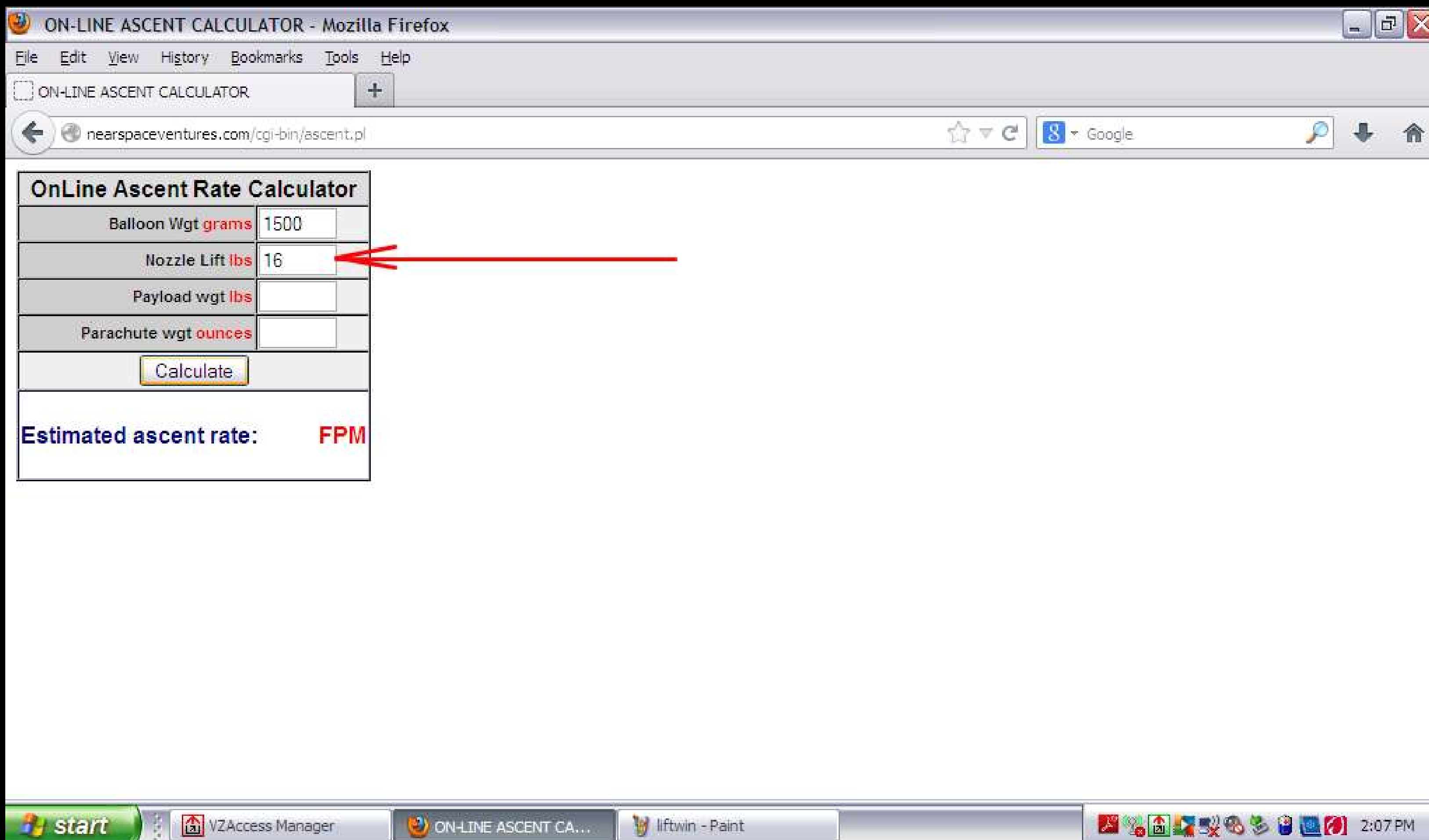
Balloon Size



Nozzle Lift



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Balloon Wgt grams 1500
Nozzle Lift lbs 16
Payload wgt lbs
Parachute wgt ounces
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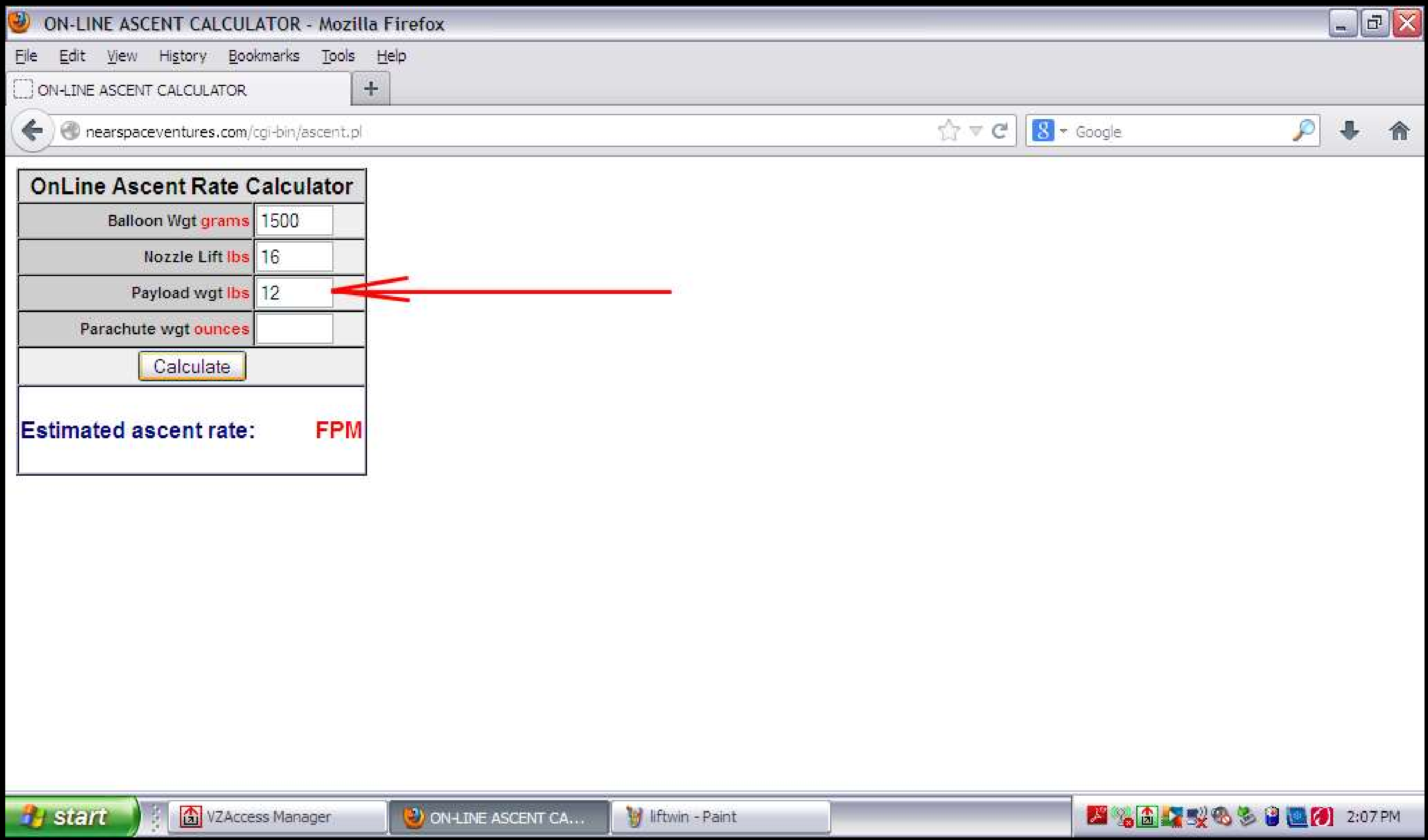
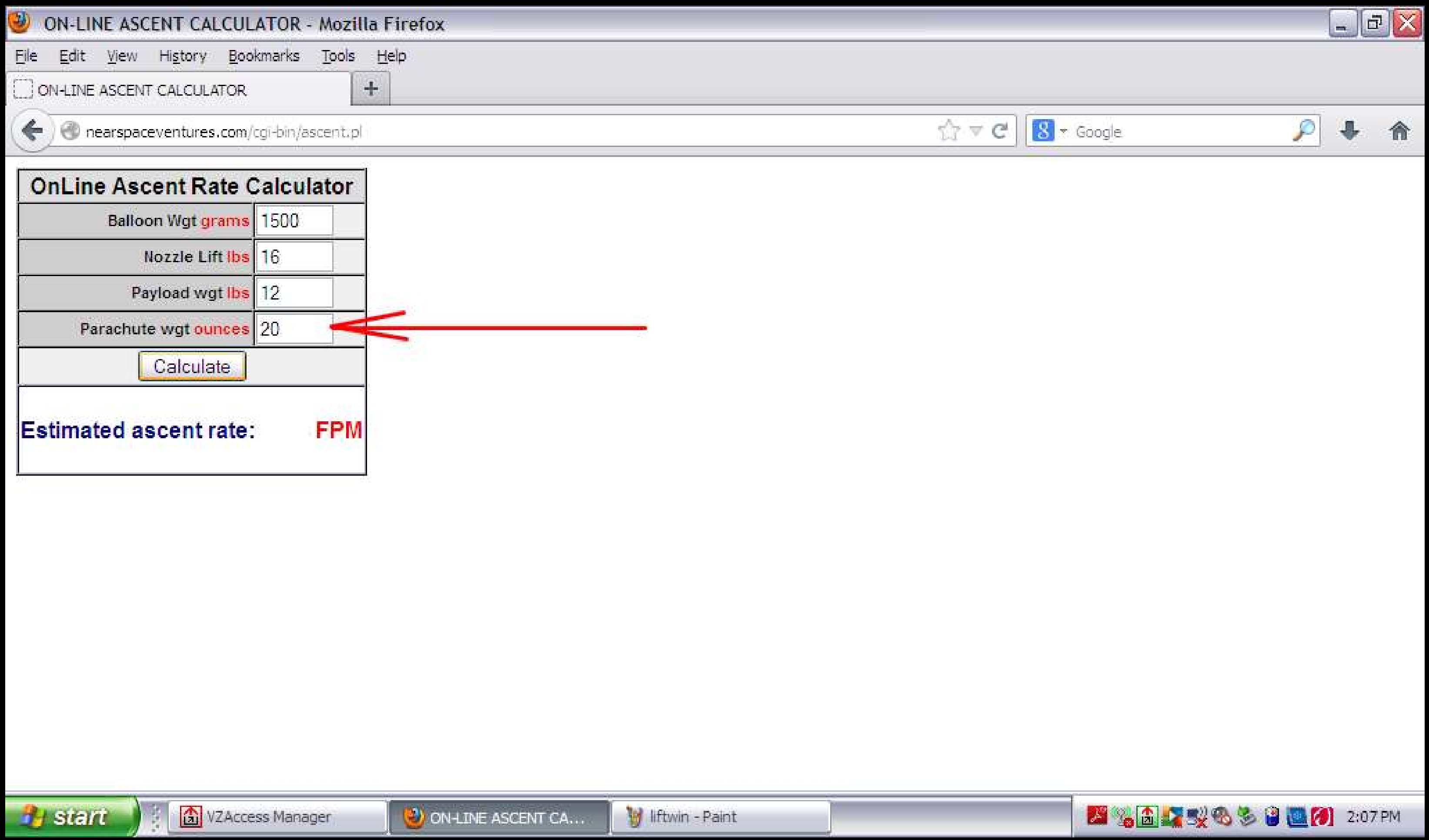
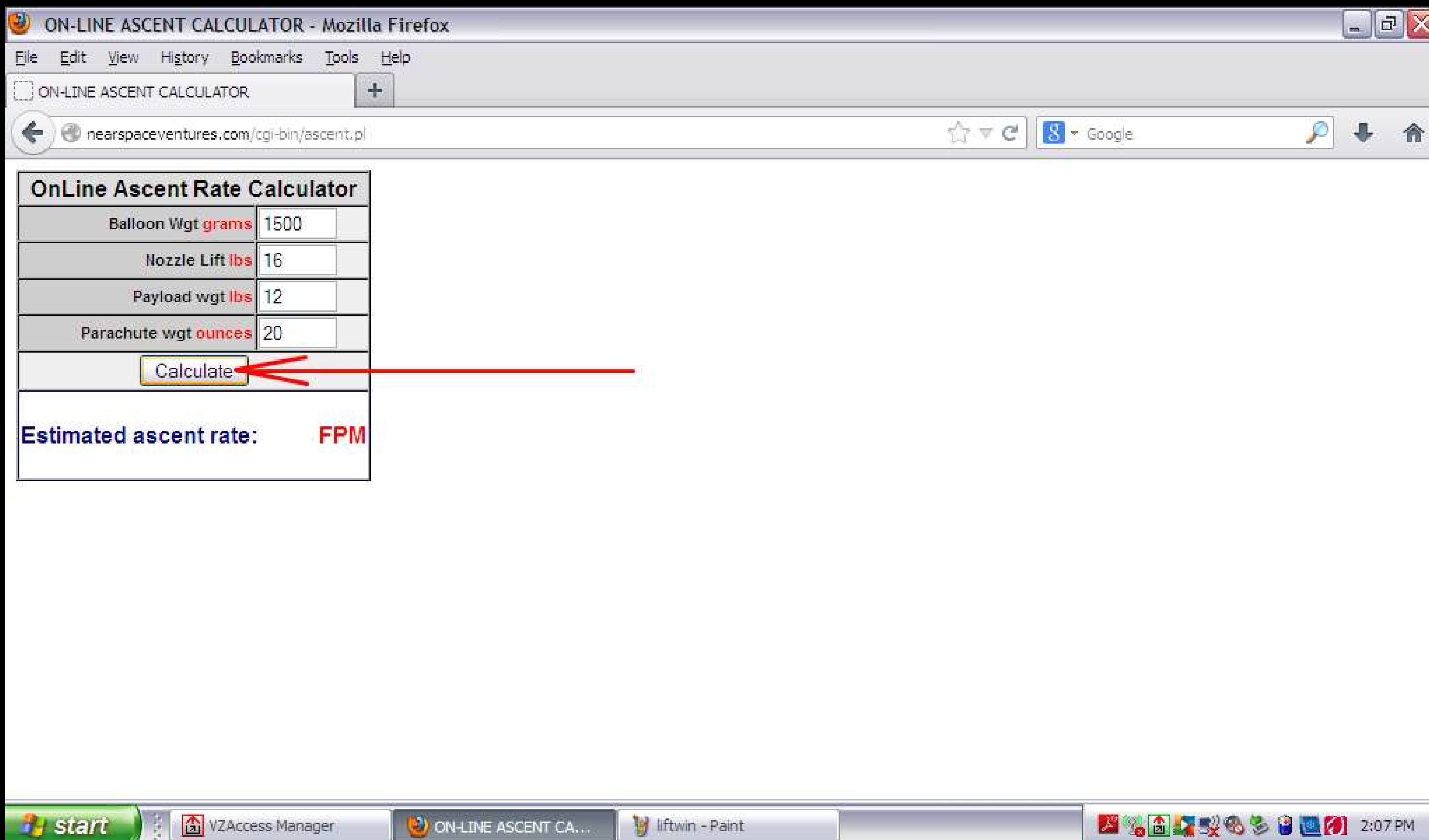
Payload Weight



Parachute Weight



Calculate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Payload wgt lbs 12
Parachute wgt ounces 20
Calculate
Estimated ascent rate: FPM
start
VZAccess Manager
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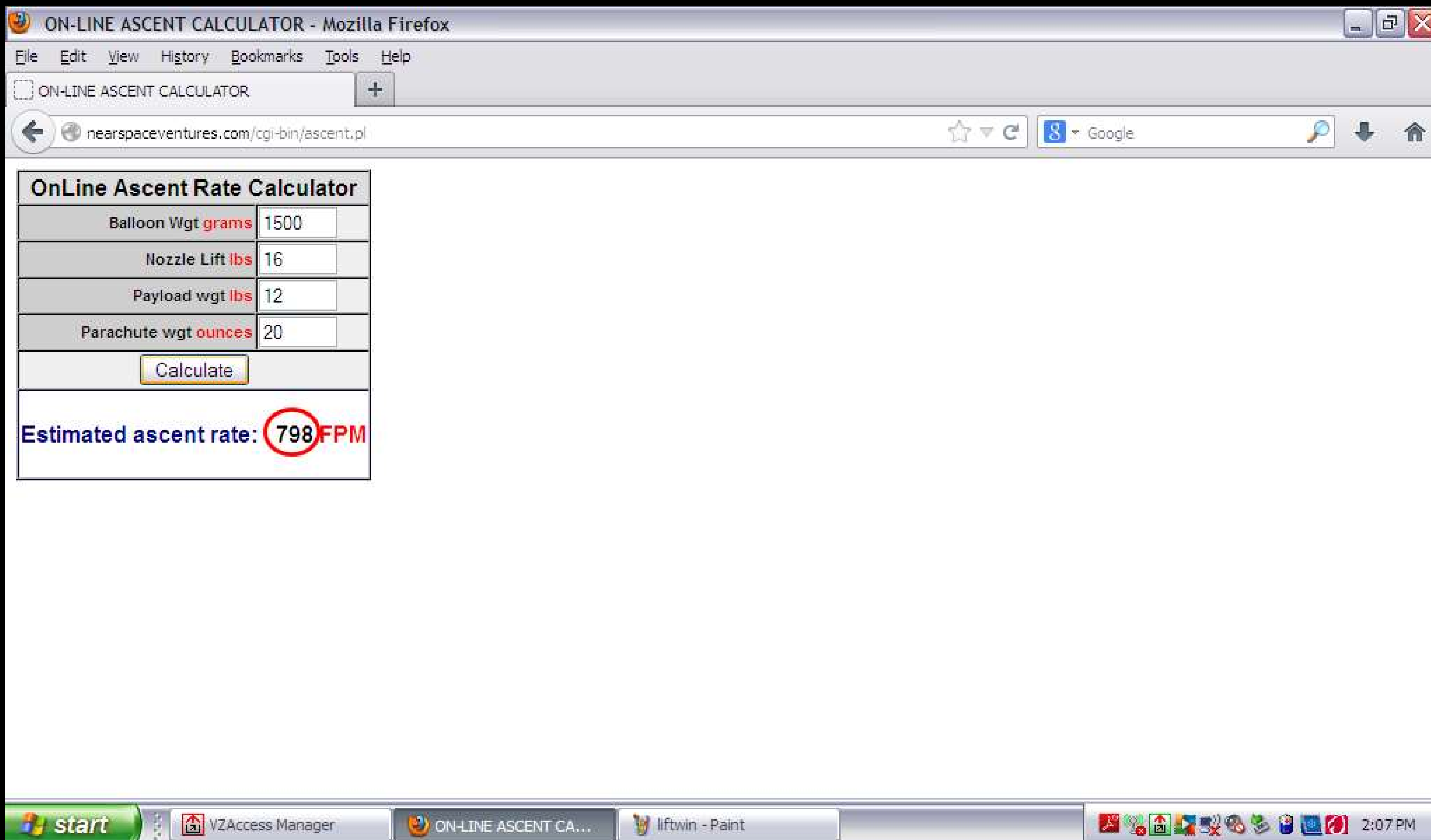
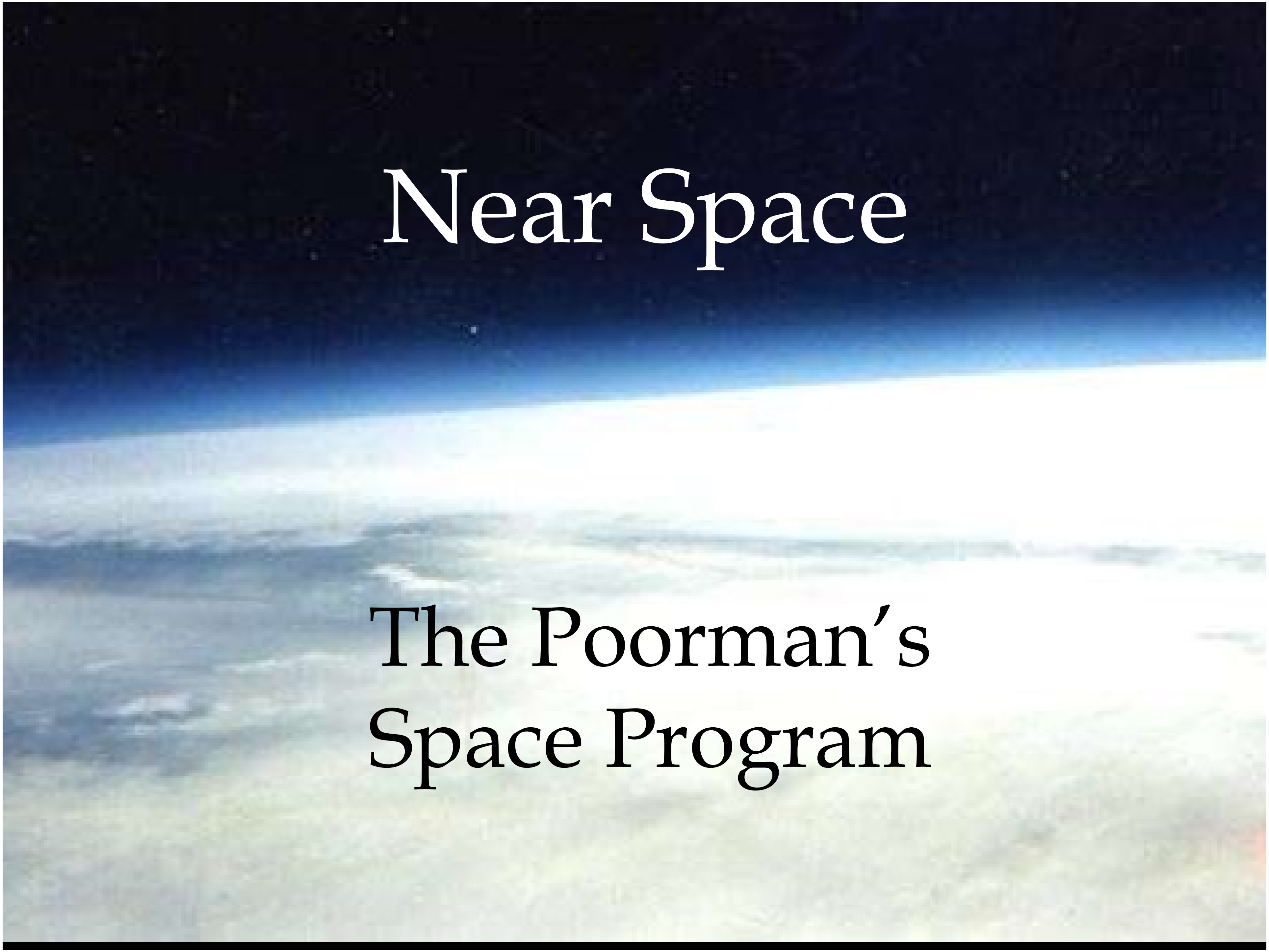
Estimated Ascent Rate



Maximum Altitude

- LiftWin online doesn’t estimate maximum altitude
- The older stand alone version does

- Try using http://www.cusf.co.uk/calc/


Near Space
The Poorman's
Space Program

Public Access To Space

- Is public access about to begin?
- Why wait when we have something nearly as good and more affordable?

Topics

- What is it Like in Near Space?
- Near Space As The Alternative To Space

Where is Near Space Located?

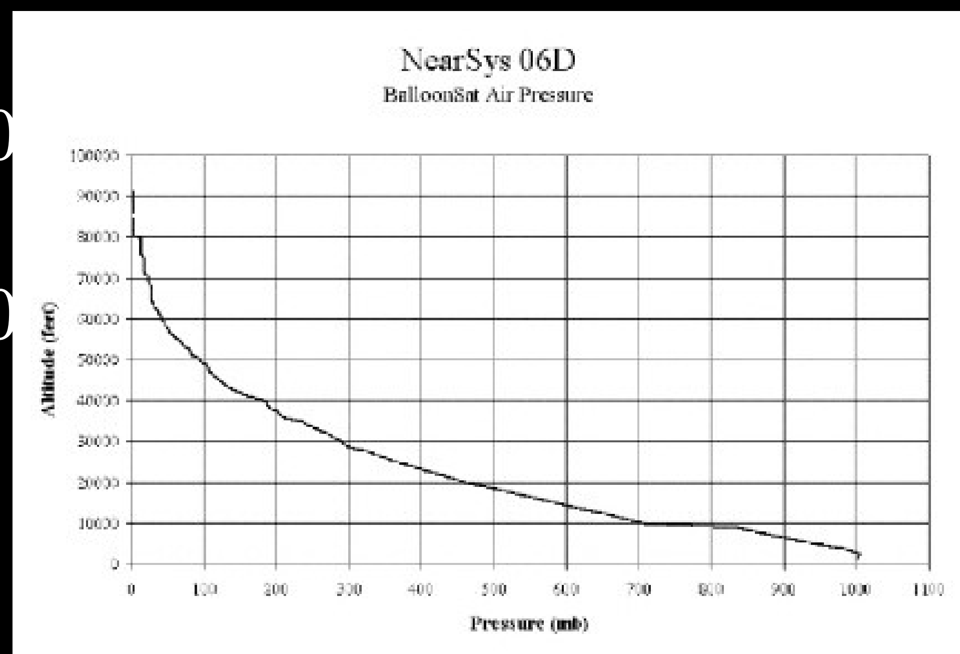
- Tallest Building: 2,722 feet tall
- Highest Mountain: 29,028 feet high
- Commercial Aircraft: 30,000 – 40,000 feet
- Lowest possible orbit: 328,000 feet

- Near Space: above 60,000 feet

Atmospheric Pressure

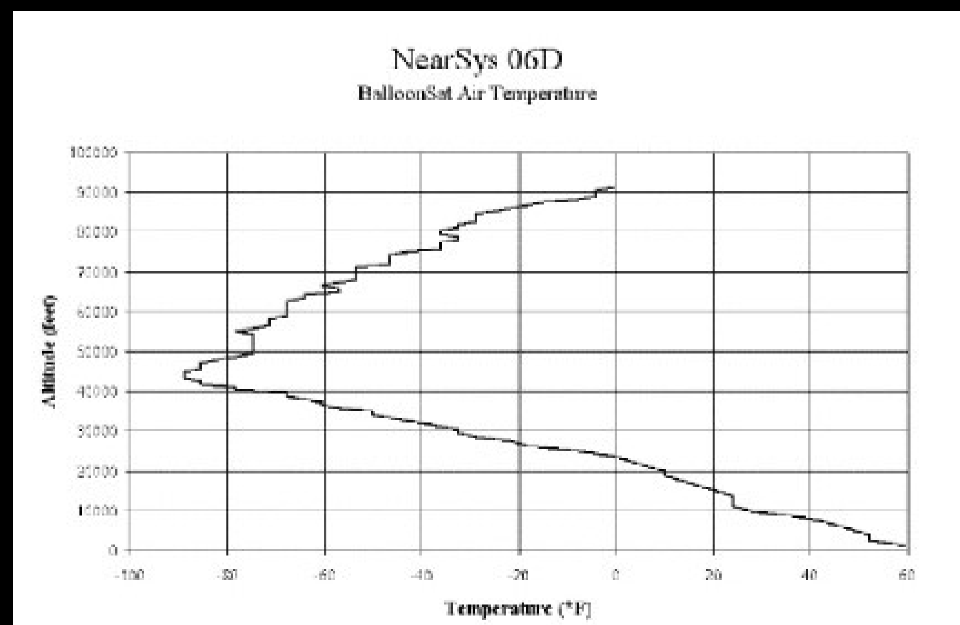
- Three Rules Of Thumb

- Changes By A Factor Of 3% Per 1000 Feet
- Changes By A Factor Of 50 Per 18,000 feet
- Changes By A Factor Of 90 Per 50,000 feet



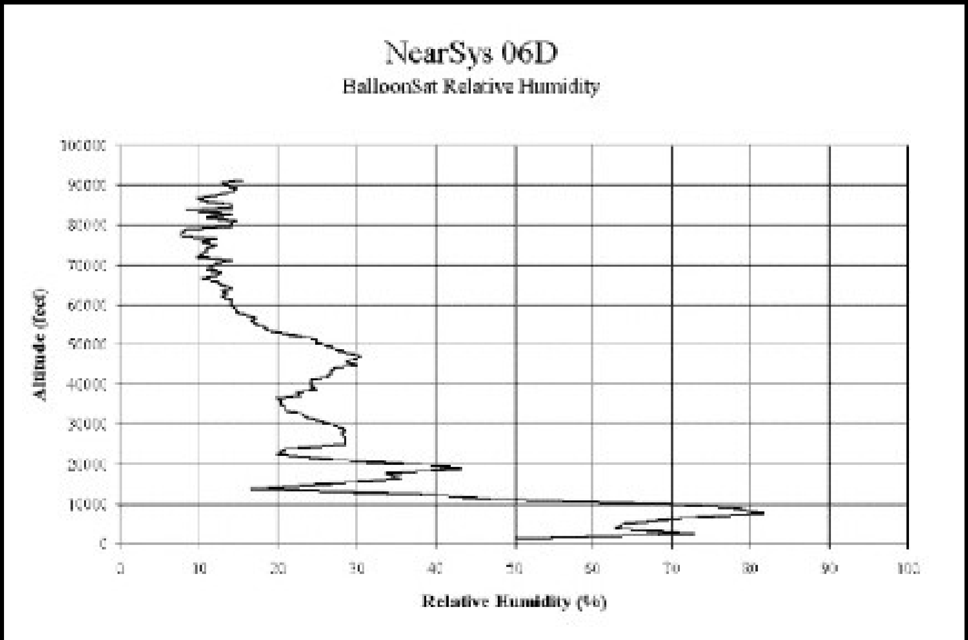
Air Temperature

- Drops As You Climb Through The Troposphere
- Rises As You Climb Through The Stratosphere (ozone)



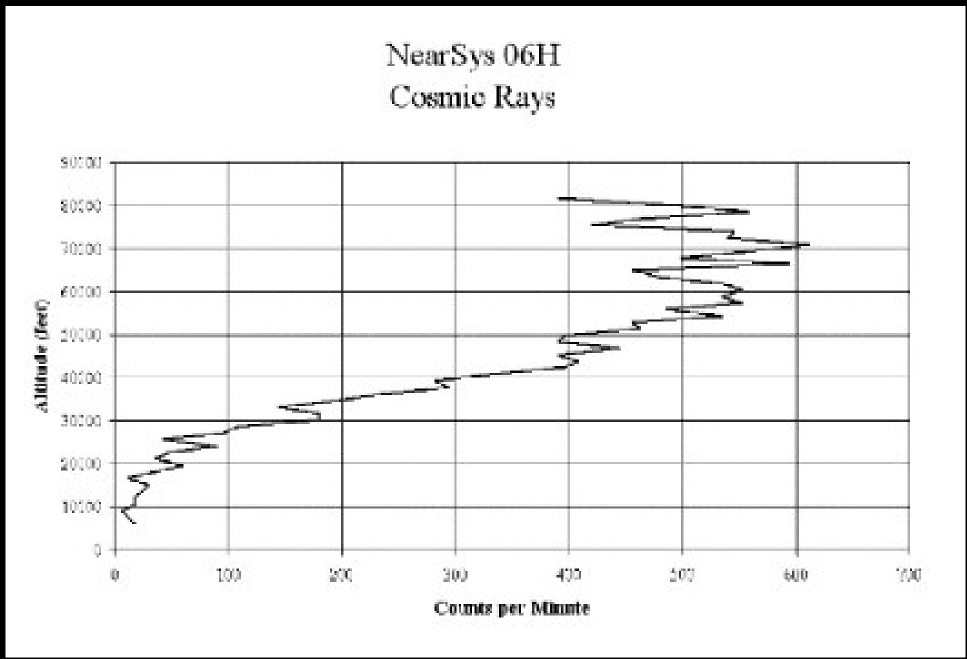
Relative Humidity

- Gets very dry
- Local peaks can indicate cloud layers



Cosmic Rays

- Primary Cosmic Rays Are Atoms From Stars
- Secondaries Created When Primaries Collide with Air Molecules
- Secondaries Further Reduced By The Atmosphere



The Near Space Horizon

- See The Entire State
- Spy On Neighboring States!

What's It Like In Near Space?

- < 5% Sea Level Pressure
- 0 to –60 degrees F
- Low Relative Humidity
- Cosmic Ray Flux 150X Greater Than Sea Level
- >300 Mile To The Horizon

Black Skies, Curved Horizon, and Primary Cosmic Rays - It Looks and Feels Like Space To Me!

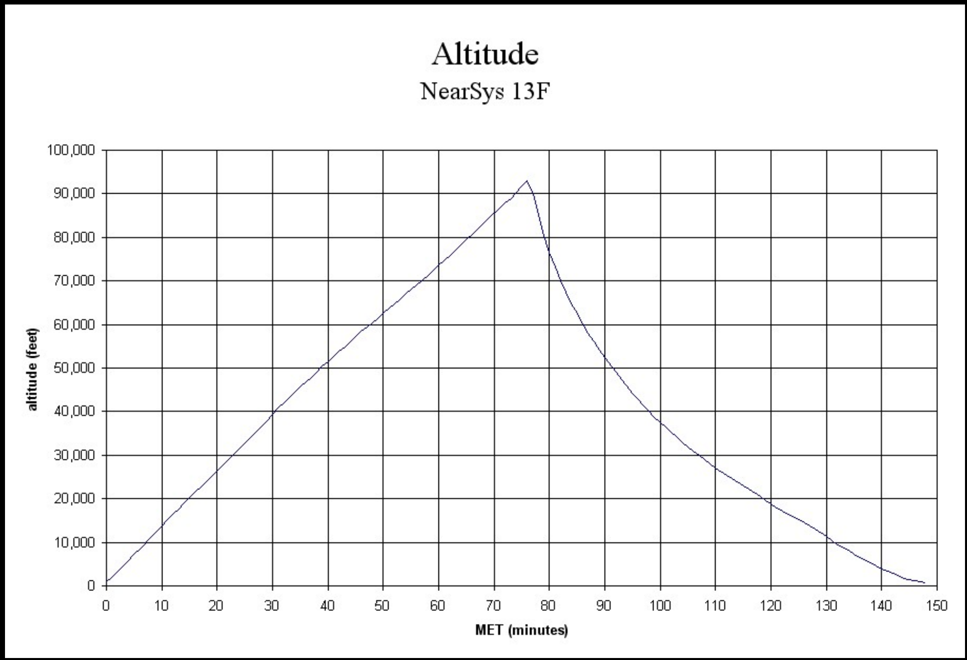
Accessing Near Space

- Helium Filled Weather Balloon
- Recovery Parachute
- One or More Modules

- Helium And The Parachute Keeps The Program Safe

The Typical Mission

- Predictions several days in advance
- Early Saturday morning
- 30 minute fill time
- 90 minute ascent
- 45 minute descent
- Done by lunch



Near Space As The Alternative To Space

- Has The Look And Feel Of Space
- It's Affordable
- It's Quick

- Two ways to explore near space

Beginning a Program from Scratch

- Ham License
- APRS
- Build Airframes
- Build Avionics
- Parachute
- Experiments/BalloonSats
- Support Equipment
- Software
- Procedures

FAR 101

- Federal Aviation Regulation 101

- Maximum Total Weight
- Maximum Module Weight
- Maximum Surface Density

- http://www.risingup.com/fars/info/101-index.shtml

Mission Support

- Preflight
  - Online prediction software BallTrak at (nearspaceventures.com)
  - Online flight performance software LiftWin at (nearspaceventures.com)
- Inflight
  - APRS (mobile)
  - Maps.findu.com/callsign
  - Aprs.fi/callsign

BalloonSats

- You design the experiment, an established group launches it

Space is Hard

- James Oberg

Near Space isn't Nearly as Hard

- L. Paul Verhage