High Altitude Balloon Carrying Amateur Radio - A STEM Learning Project

The Nashua Area Radio Society

Nashua Area Radio Society
N1FD

v21

Our Sessions

Weekly Format

1. A: Project Introduction – What will we be doing?
   B: Balloon Physics 1 – Forces effecting our HAB's flight and burst altitude
2. C: Balloon Physics 2 – HAB's weight and burst altitude revisited
   D: The Atmosphere – Temperature and Pressure our HAB will encounter
3. E: Descent through the Atmosphere – Parachute operation
   F: HAB Flight Path Prediction – It's mostly about the Jetstream
4. G: HAB Tracking and Radios 1 – Following our HAB and its data
   H: HAB Tracking and Radios 2 – Hands on with Tracking Tools
5. I: Space Communications – What's up & how do we communicate using it?
   J: Launching Our HAB – Final preparations (classroom or during Open House?)
   Amateur Radio Open House
6. K: Post-flight Data Analysis (may be two, 1 hour sessions…)
   L: Preparing Our Project Report

High Altitude Balloon Carrying Amateur Radio

Project Introduction – What will we be doing?

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High Altitude Balloon

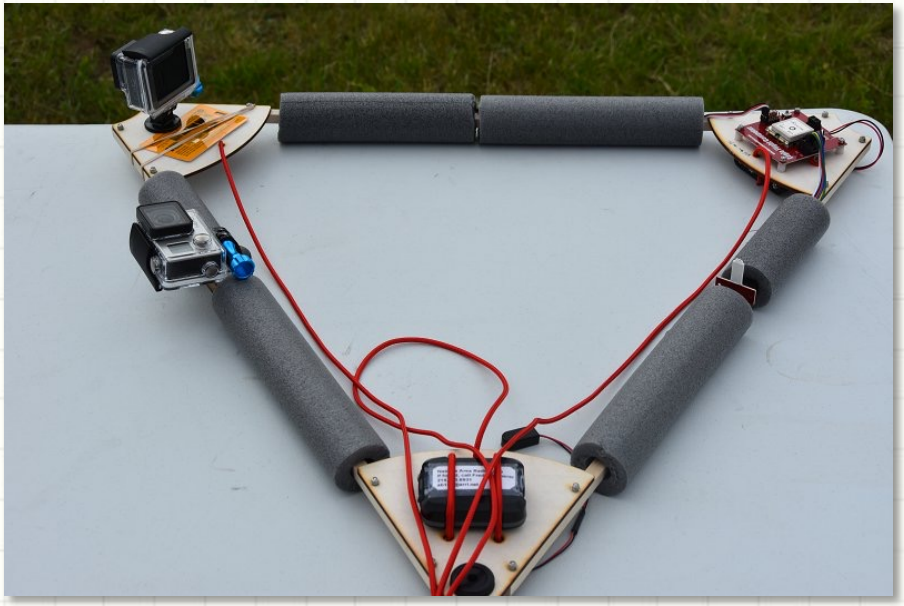
What will we be doing?

- Helium filled balloon carries < 4 lb. payload to altitude ~ 100,000+ ft
  - Parachute controls decent rate after balloon bursts
- Video of flight using on-board GoPro lightweight camera(s)
- On-board radio transmitter allows in-flight tracking via Internet
  - Flight computer records data throughout the flight
- On-board experiments will help us learn about the atmosphere
- Hands-on activities include –
  - Plan the flight path
  - Make design decisions
  - Plan science experiments
  - Test the payload
  - Launch, track & recover the payload
  - Analyze & present experimental results
  - Help to define our goals for additional launches after the initial one

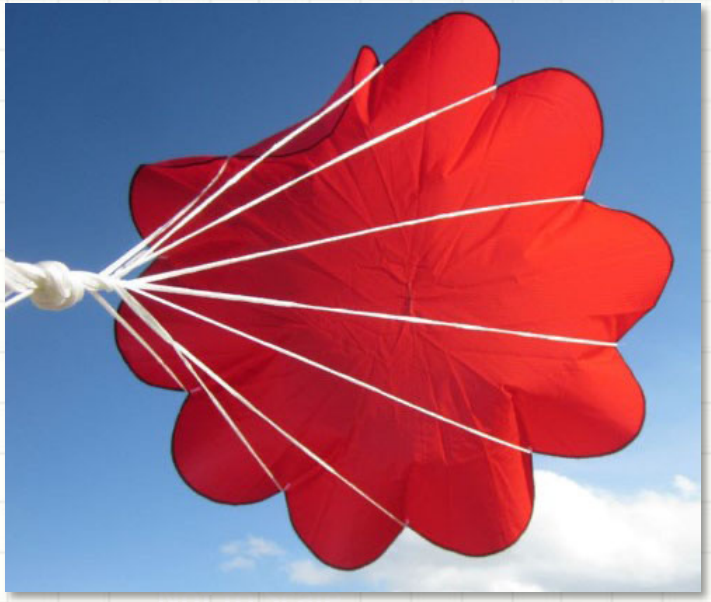
High Altitude Balloon

What is it?

HAB During Ascent

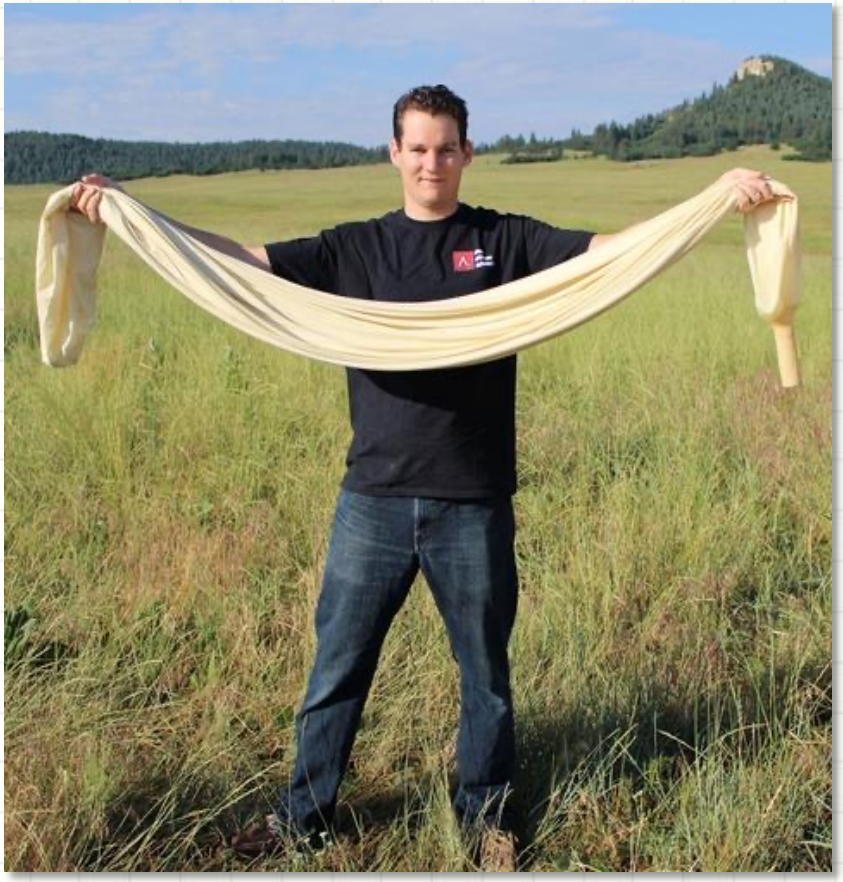


Flight Platform & Parachute



High Altitude Balloon Project

Weather Balloons

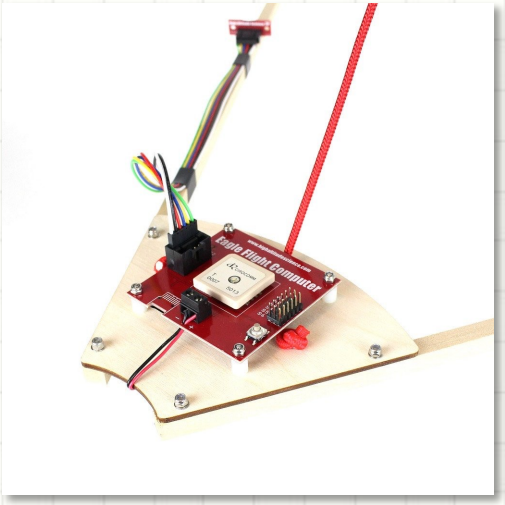


Large Balloon
(6-8 ft in diameter on ground)

Burst Diameter
(30+ ft at final altitude)

High Altitude Balloons

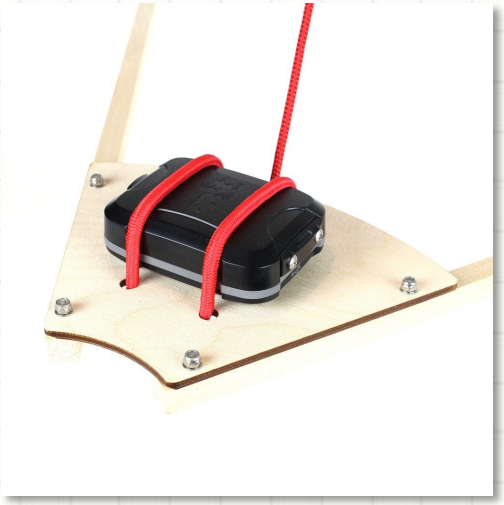
Payload Components



Flight Computer

GoPro Camera

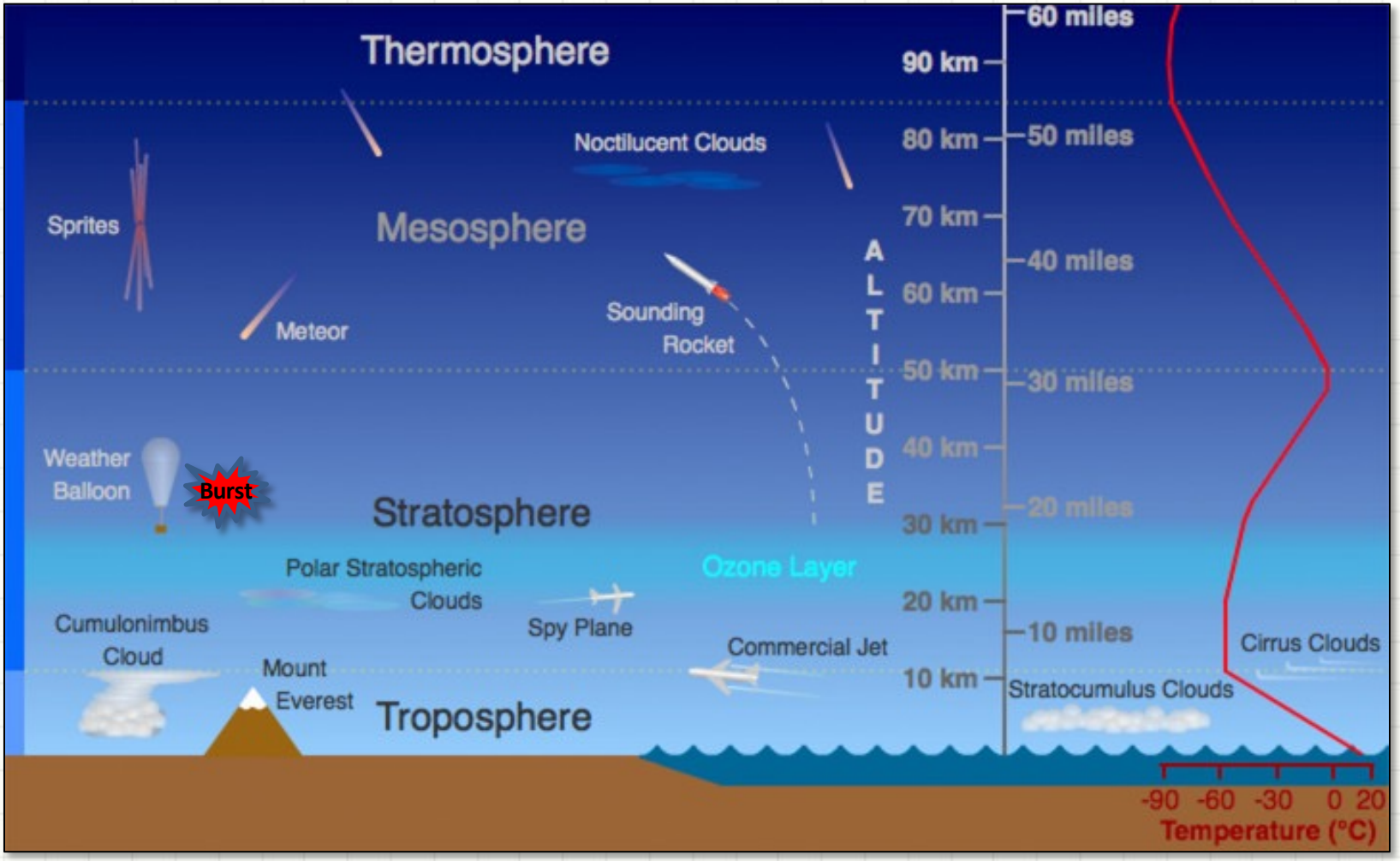
APRS Radio Transmitter



Commercial Satellite Tracker

Layers of the Atmosphere and Temperature

What we might see



Our HAB is going to reach a maximum altitude of about 30 km, so we explored the lower two layers in the atmosphere

High Altitude Balloons

What Will The Flight Be Like?

Vimeo link to HAB
Overview video

Predicting the HAB's Flight Path

Burst Calculator

Required Helium (in cubic feet)

124.38834896598486

Estimated Burst Altitude (in meters)

31290

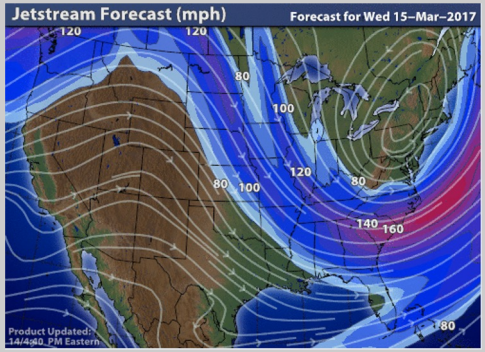
Average Ascent Rate (in meters/second)

5.240119821856709

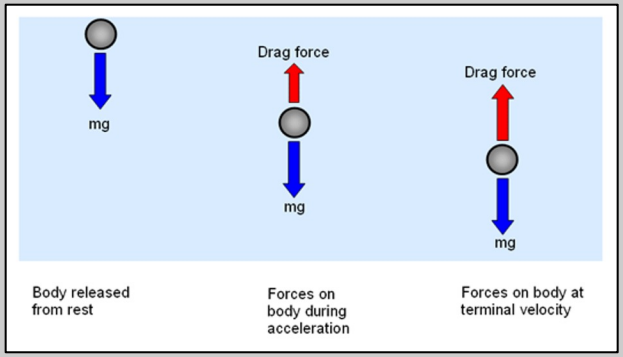
Ascent Time (in minutes)

99.52062504845914

Jetstream



Terminal Velocity

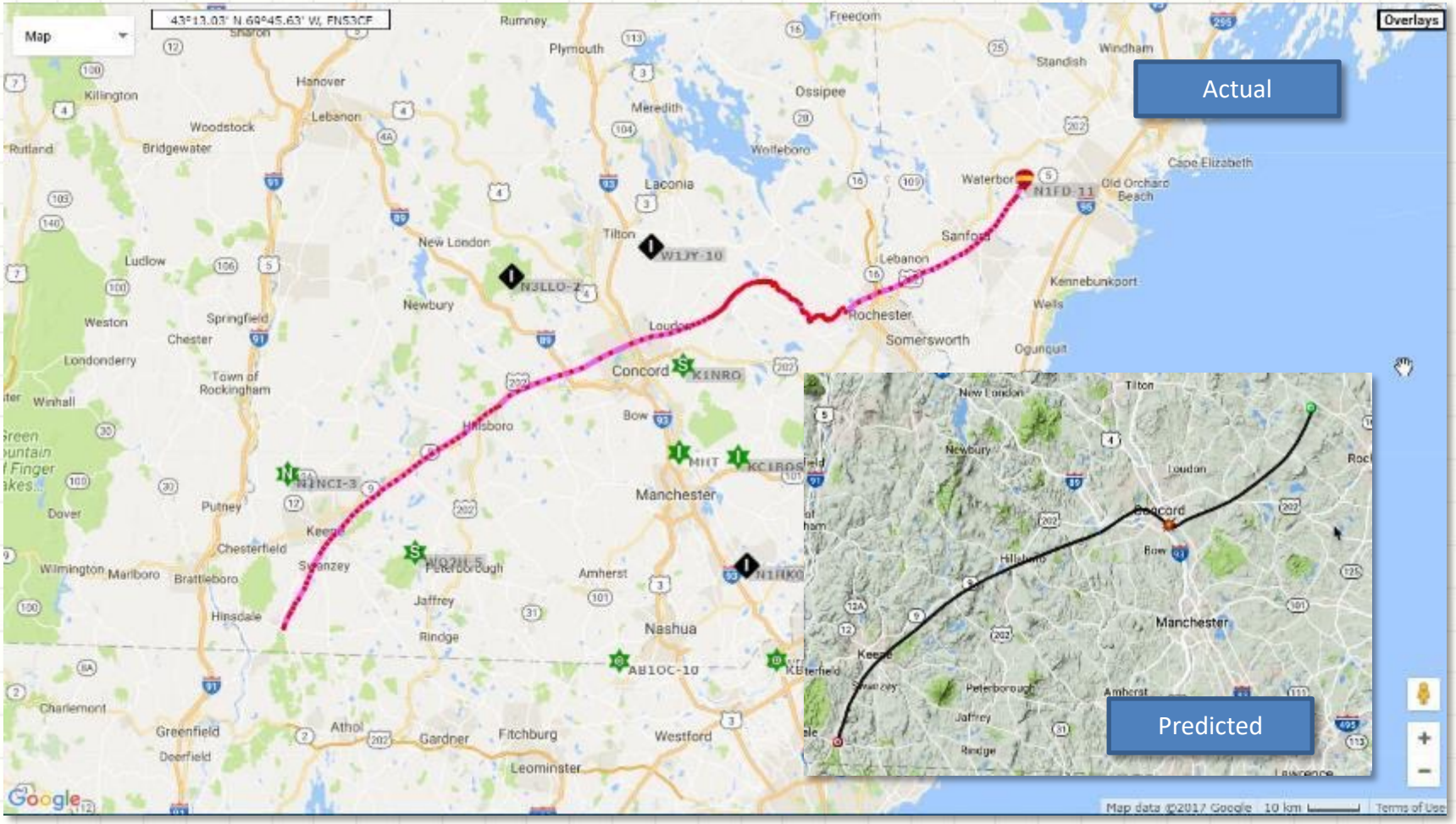


Flight Path Predictions

We will use physics, math, and some tools to design our HAB's flight and predict its path

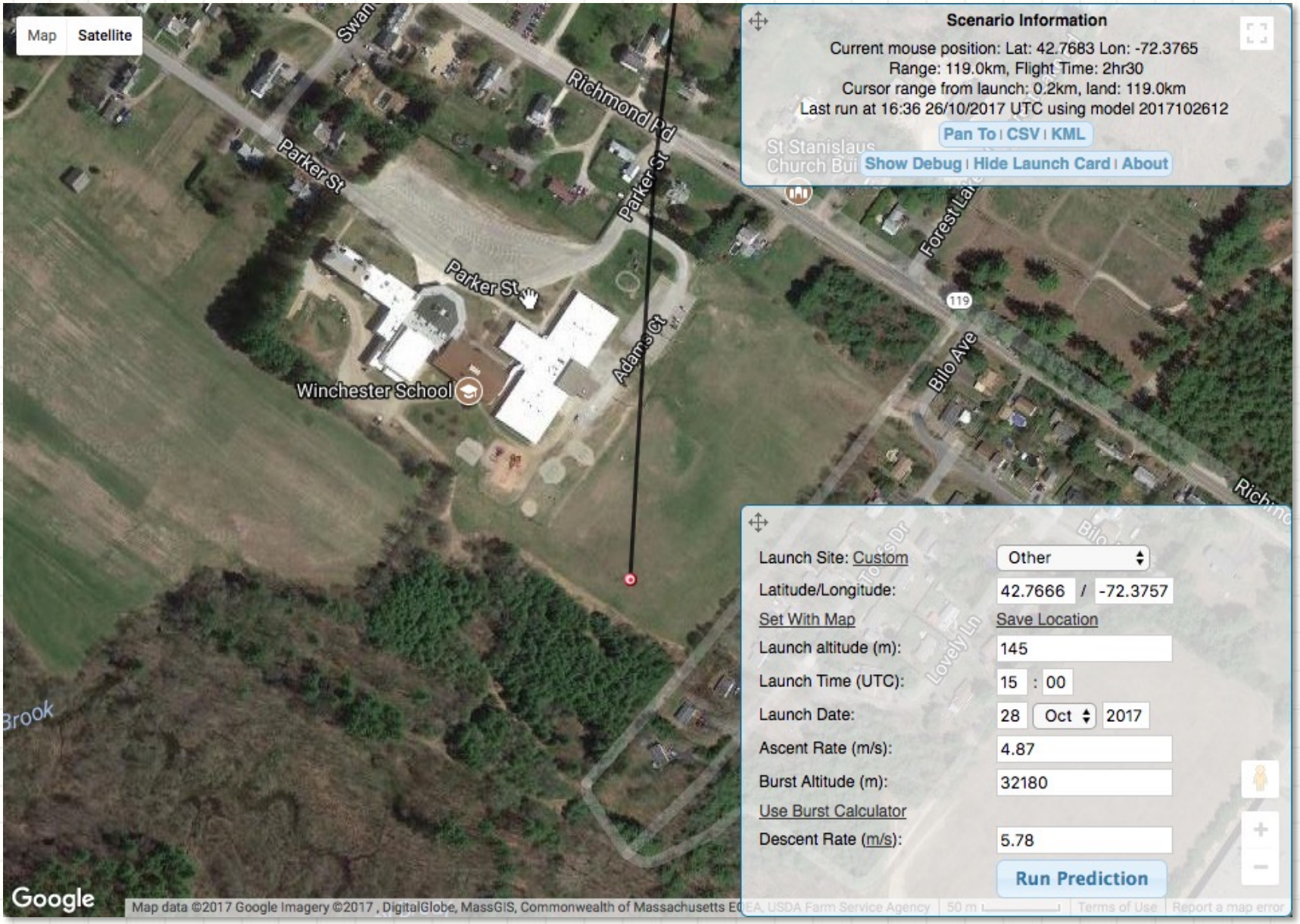
HAB-2 Flight Path

Actual vs. Predicted

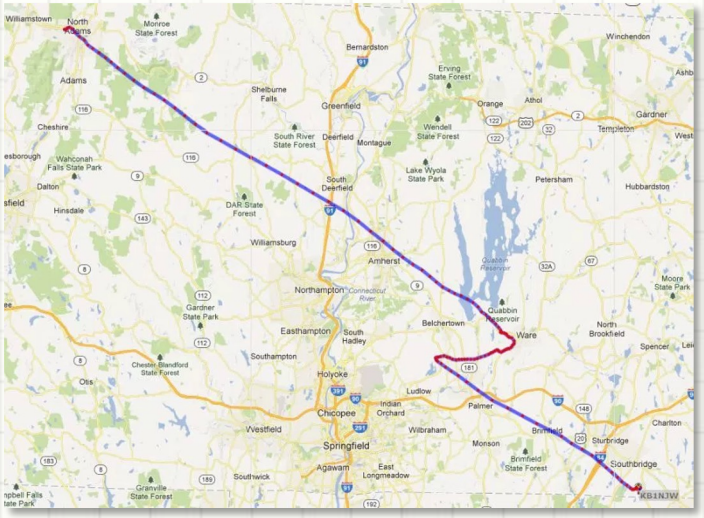


HAB-2 flew further, longer and higher than predicted –
Probably not quite enough Helium in the Balloon…
(Actual Burst Altitude was ~118,000 ft or ~ 22 mi)

Winchester NH Launch Site

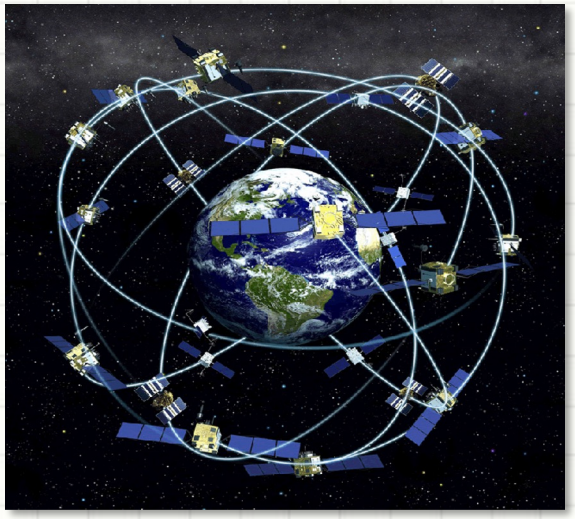


Tracking the HAB – Its All About Radio



Predictions

- On board radios provide actual position to ground stations for tracking
- **GPS = Global Positioning System**: HAB location and altitude
- **APRS = Automatic Position Reporting System**: Relays GPS data to ground stations
- We with use Amateur Radio Frequencies to track our HAB and receive data



GPS

APRS

HAB Launch and Recovery

What will it be like?

- ✓ We will gather at the launch site on at 9 am to prepare for an 11 am launch
- ✓ Our HAB's flight will take 2 ½ - 3 hours
- ✓ Will use tablets, smartphones, or a laptop to track the HAB while it flies
- ✓ Our recovery team will be located near the landing point that we predict
- ✓ Recovery team uses radio direction finding to locate our HAB

HAM Station Visit

Learn About Communications

- Tour an Amateur Radio station and learn about Amateur Radio Communications
- Get on the air and talk to Amateurs around the world
- Make a contact through a satellite in space
- Radio direction finding to locate a hidden radio transmitters
- Learn about what's involved in getting a Ham Radio License and what you can do with it

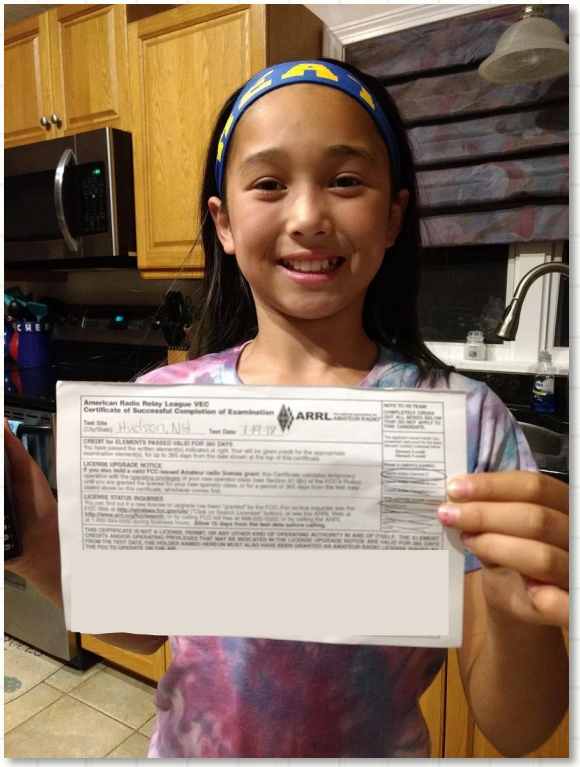
Licensing and New Ham Development: Ham Radio Bootcamp

Edit

TOPICS	DATE
HT Programming Getting Started with EchoLink Join the Repeater Net Fox Hunting Shack Open House and Tour at AB1OC/AB1QB	Saturday, March 9th 10:00 am - 2:00 pm
Satellite Operating Session Learn to Operate Digital HF GOTA SOTA (Summits on the Air) Intro	Saturday March 16th starting After the NARS Breakfast (Around 10:00 am) to 2:00 pm
How to pick a Radio Commercial Antenna Options Group Trip to Ham Radio Outlet in Salem with Elmers	TBD
Build an Antenna for VHF/UHF How to pick an antenna and tune it up	TBD
How to setup an HF Station HF Radio Choices Building, tuning, and putting up a first HF Antenna Getting on 6 meters Mobile HF	TBD
New Ham Contest (ARRL Rookie Roundup SSB)	Sunday, April 14th
Hands-on Field Day Visit	Friday - Sunday June 21st - 23rd
Join the Spring HAB Launch	May / June TBD

License Classes – Sign Up Now!

- Winter/Spring License Class Schedule:
  - General – March 23-24
  - Extra – April 26-28
- Classes held at Dartmouth-Hitchcock Nashua
- Based on Gordon West License Manuals
- Sign up on www.n1fd.org



- Successful Technician Class held February 23-24!
- 13 students – all passed the Technician exam!
- 3 walk-ins for VE session earned Technician, General and Extra licenses
- Thanks to instructors and VEs

High Altitude Balloon Carrying Amateur Radio

Balloon Physics 1 – Forces Effecting Our HAB's Flight and Burst Altitude

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Predicting the HAB's Flight Path

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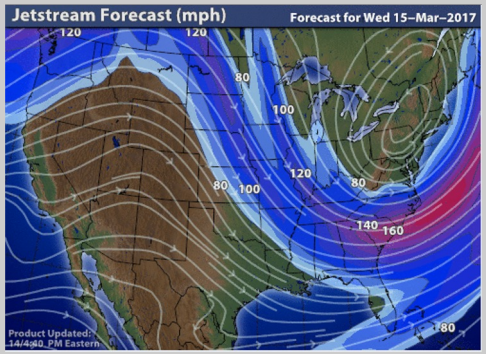
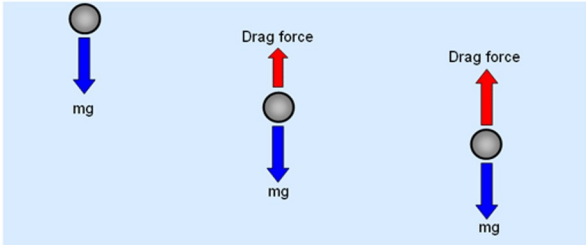


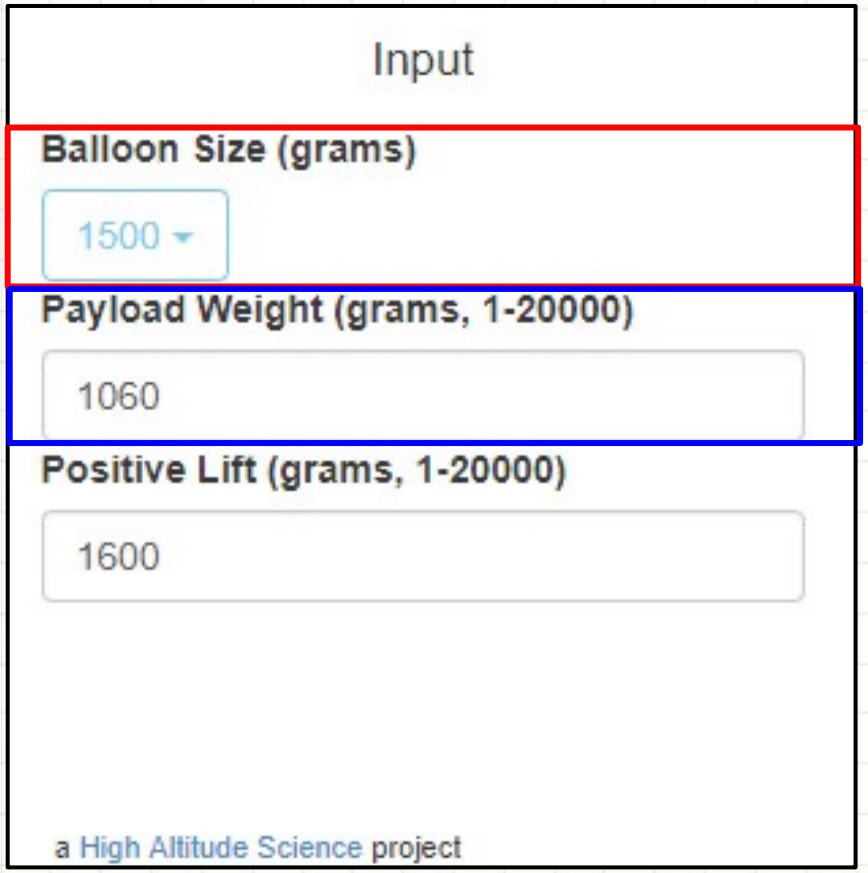
Terminal Velocity

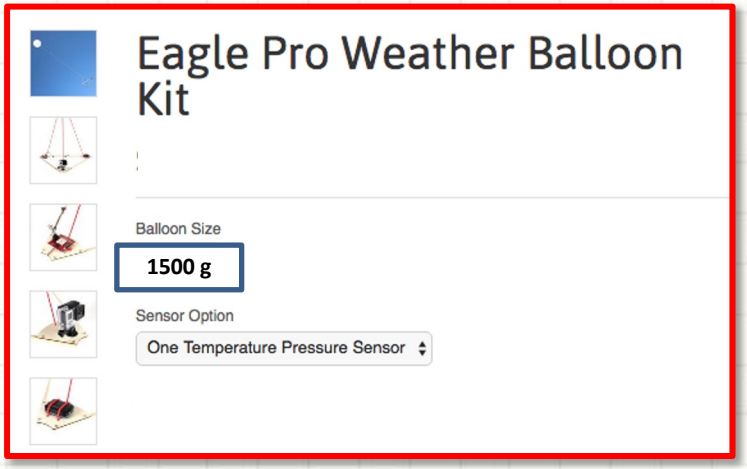


Flight Path Predictions

The HAB's Ascent - Balloon Calculator

http://tools.highaltitudescience.com/#



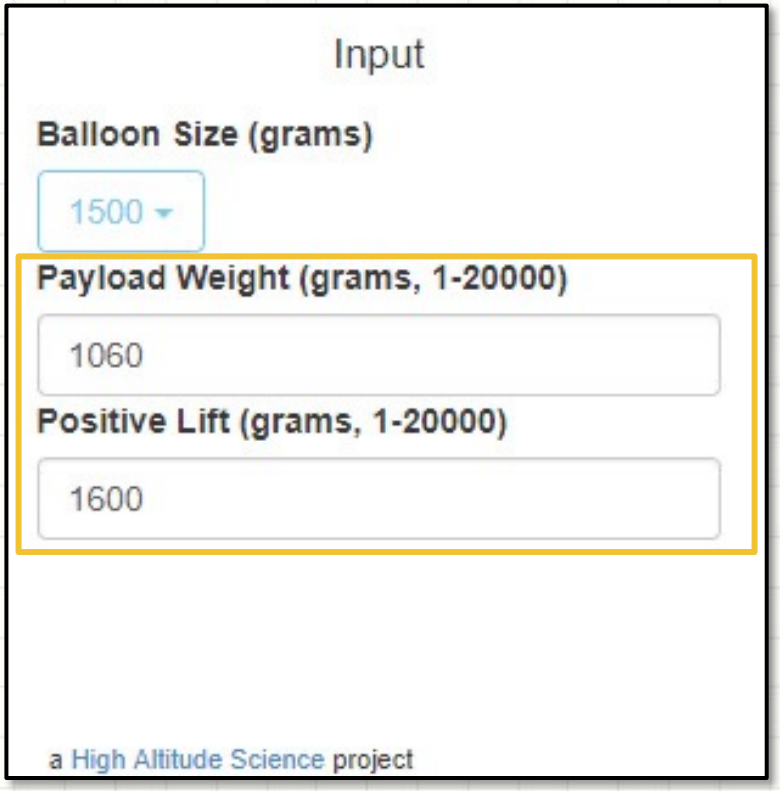


APRS

GoPro Hero 3

We'll work with the calculator soon, but first let's understand the inputs, outputs, and some of the science behind it

HAB Balloon Calculator Inputs



- Lift is the amount of force to make the balloon float
  - Helium is less dense than air
- Lift directly opposes the **force of gravity**
- Specifying the amount of lift is also specifying how much Helium is needed
- Another way to understand lift is to study **buoyancy**
  - Air is another type of fluid

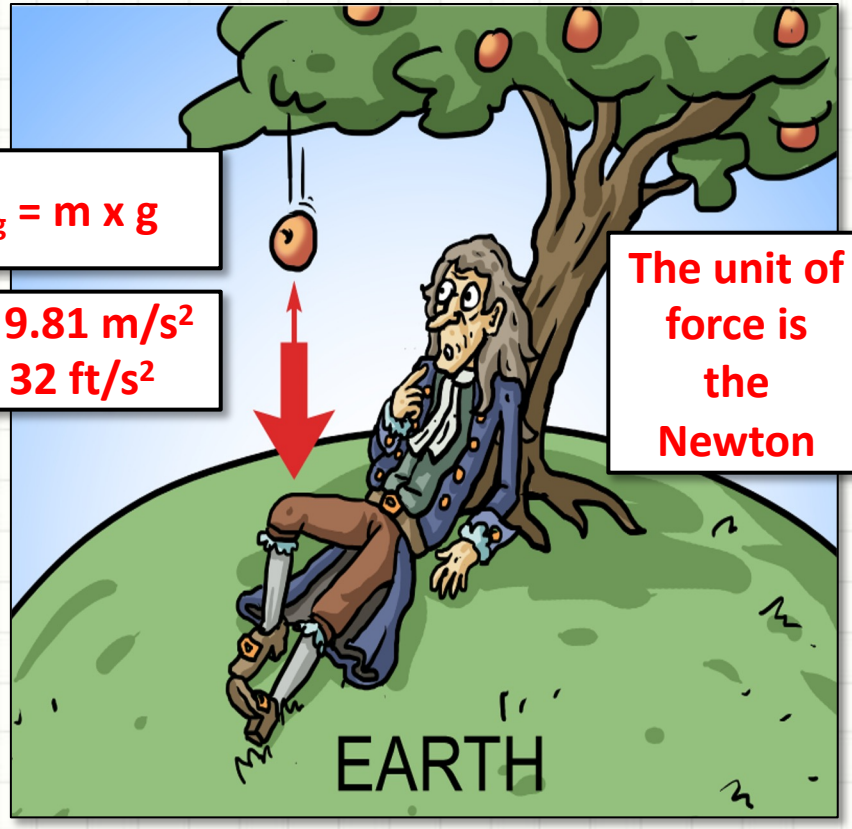
In the next sections will briefly explore the force of gravity and buoyancy

The Force of Gravity

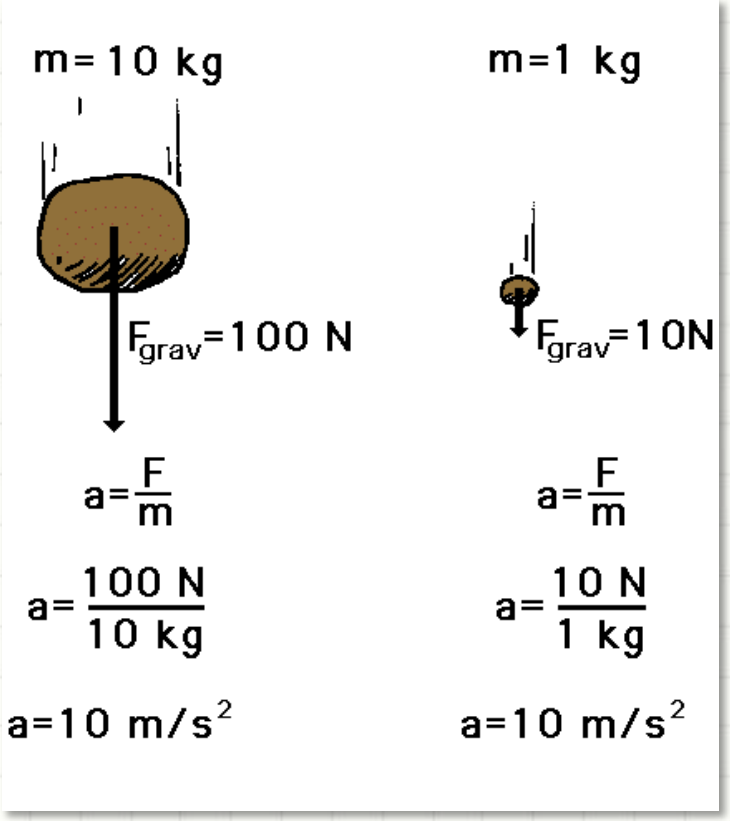
Newton and Galileo

$F_g = m \times g$

$g = 9.81\ m/s^2$
$= 32\ ft/s^2$



The unit of force is the Newton



The force of gravity equals the mass of the object times the gravitational acceleration, *g*

Change in Velocity = g x t
in a vacuum where there is no air resistance.

YouTube Video

Acceleration Due to Gravity in a Vacuum

The HAB and Projectile Motion

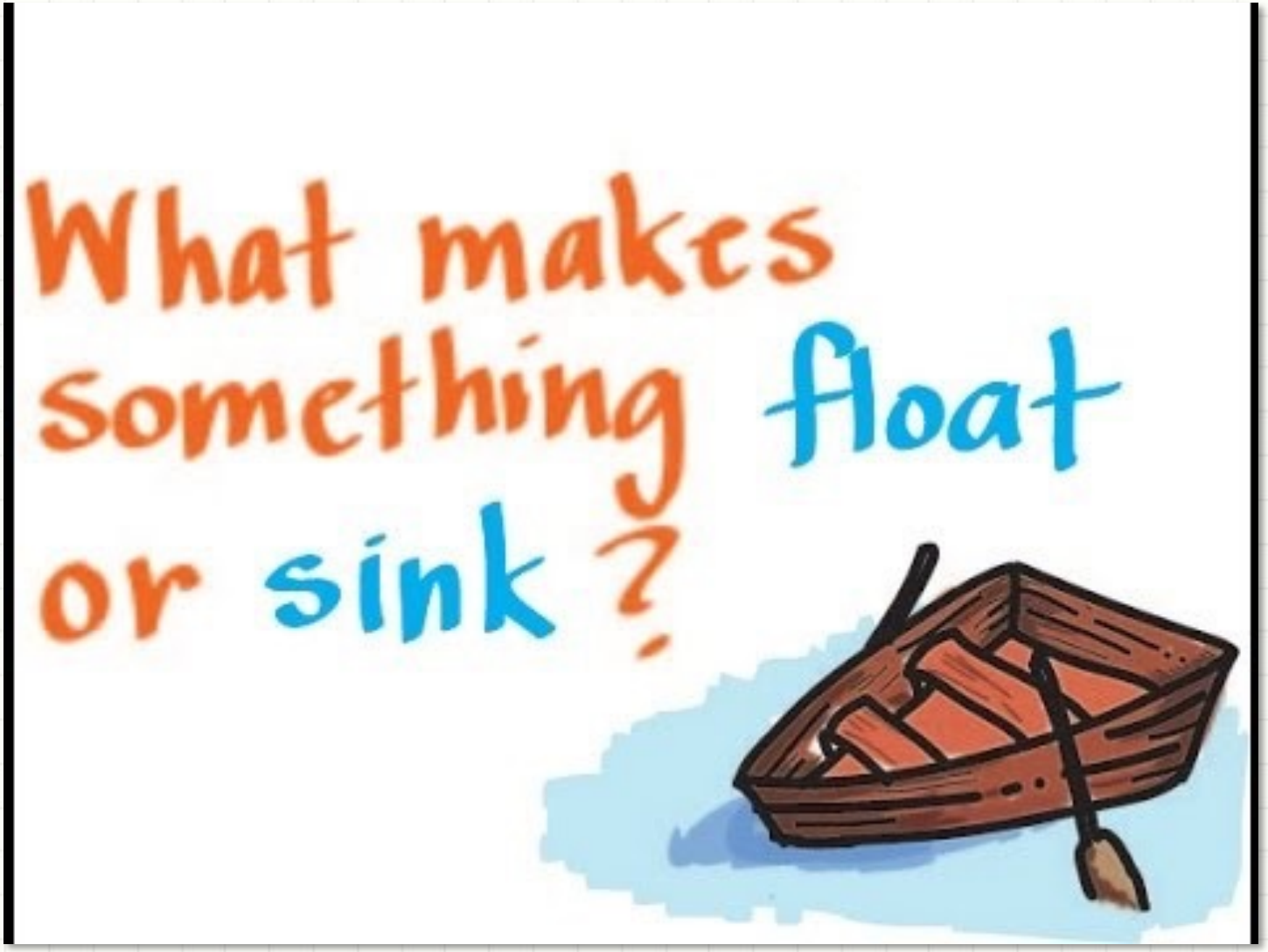
Next, we will examine what causes the balloon to ascend

- During the descent, *in the absence of drag from the air,* the **vertical** acceleration of the balloon is due to force of gravity
- Any **horizontal** accelerations will be due to the Jetstream and prevailing winds
- When our balloon bursts at the edge of space, there will be very little air. Just after burst, our HAB should fall at a rate much closer to ***g***; the gravity acceleration constant.
- Drag force is VERY important. It prevents the balloon from accelerating indefinitely and helps it reach a max speed known as **terminal velocity**. More to come on this later.

Buoyancy

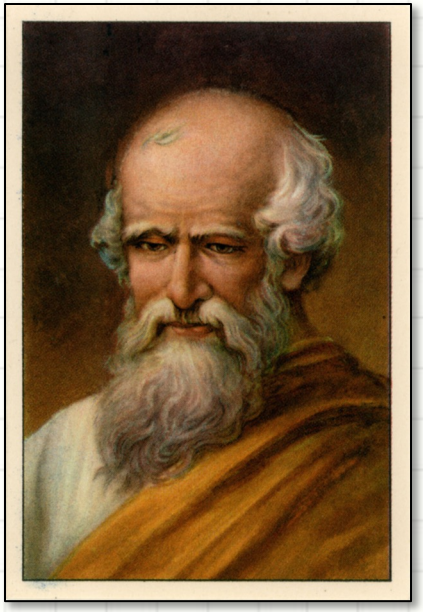
YouTube Video

Concept at work: Archimedes' Principle



Archimedes' Principle

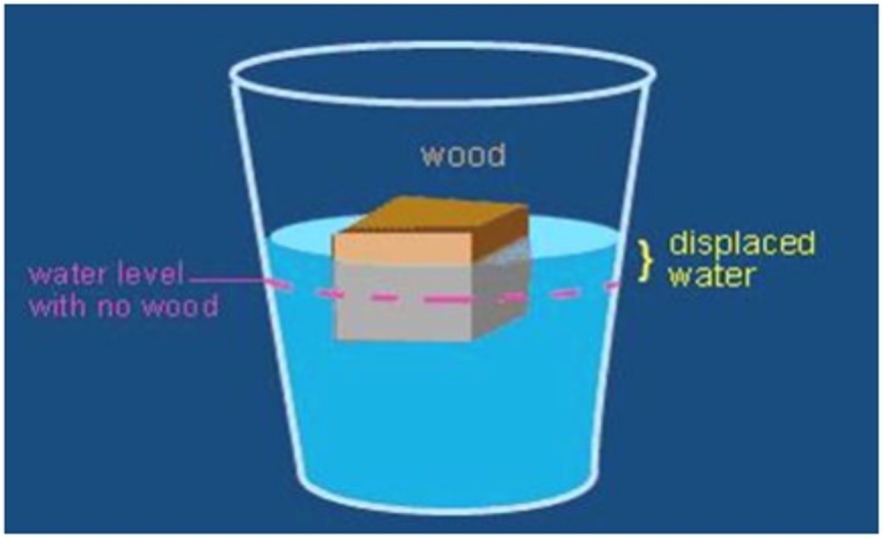
Archimedes
of Syracuse



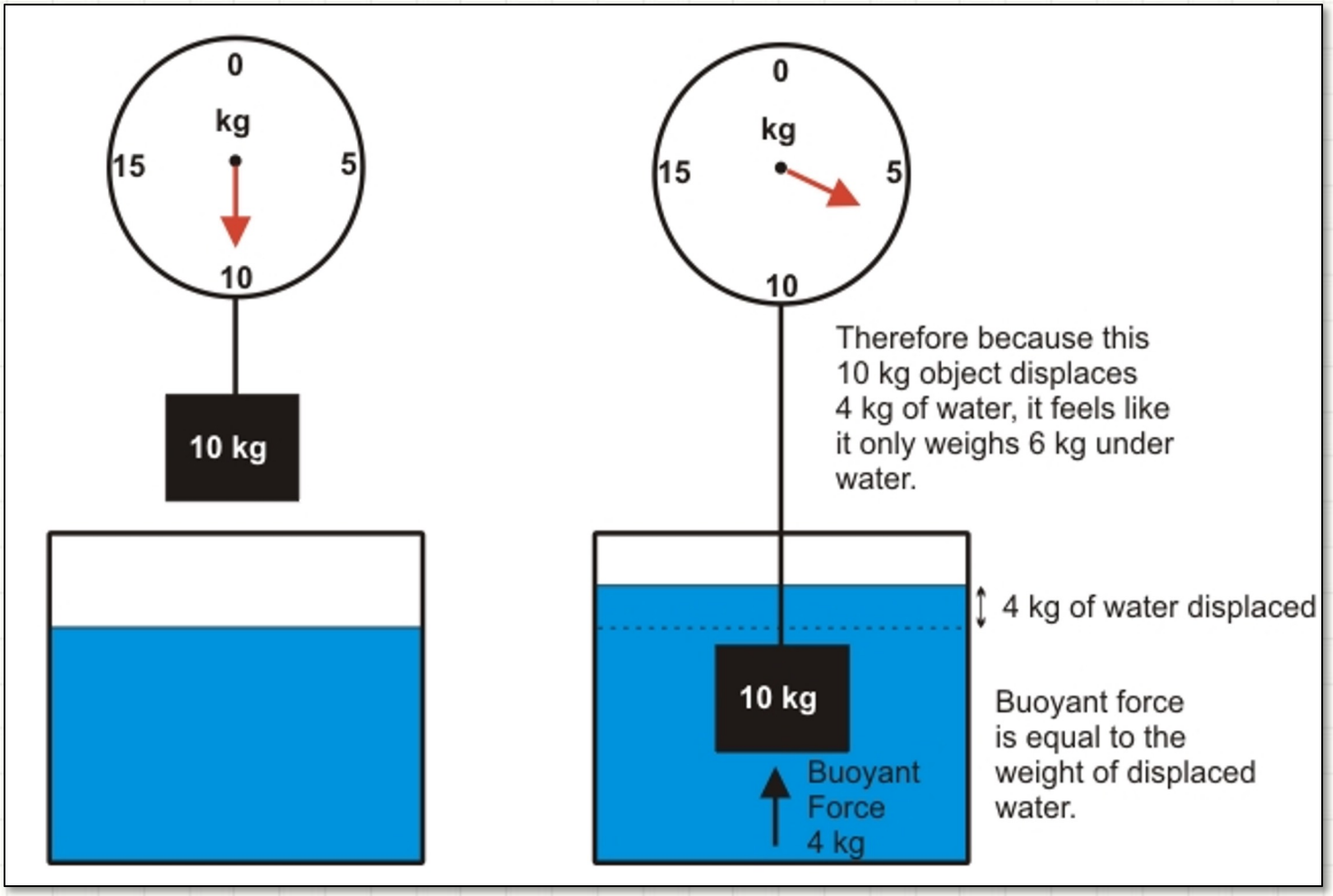
- Ancient Greek mathematican
- Shouted *Eureka* when he discovered buoyancy

Archimedes' principle

- the buoyant force of an object is **equal** to the **weight** of the fluid **displaced** by the object



Buoyant Force Example



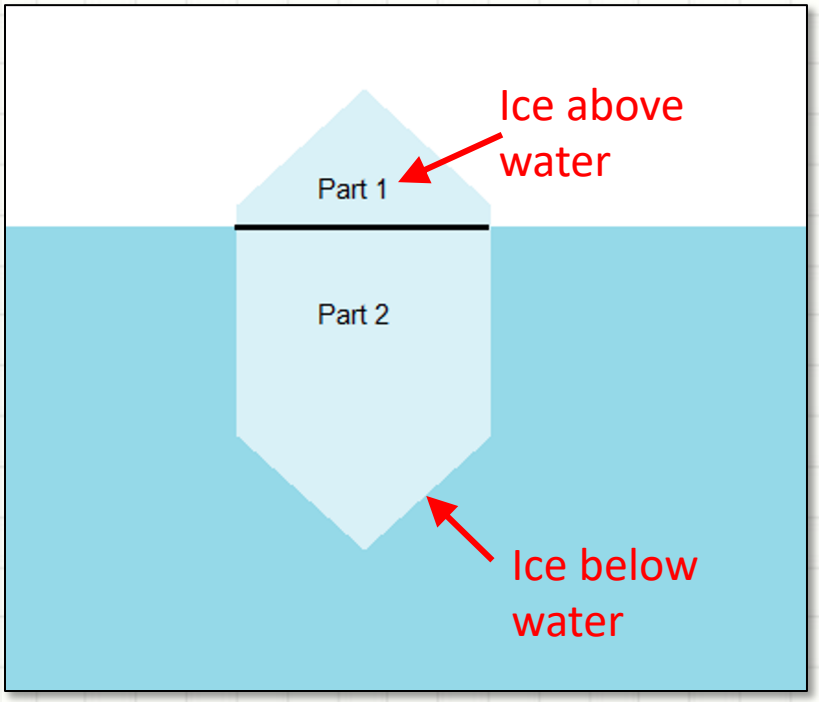
The buoyant force serves to reduce the apparent weight of an object while in a fluid

Buoyant Force Quiz

If a an ice cube floats in a glass of water, what happens to the level of the water in the glass when the ice melts?

Take a few minutes and work with a friend to try and figure it out.

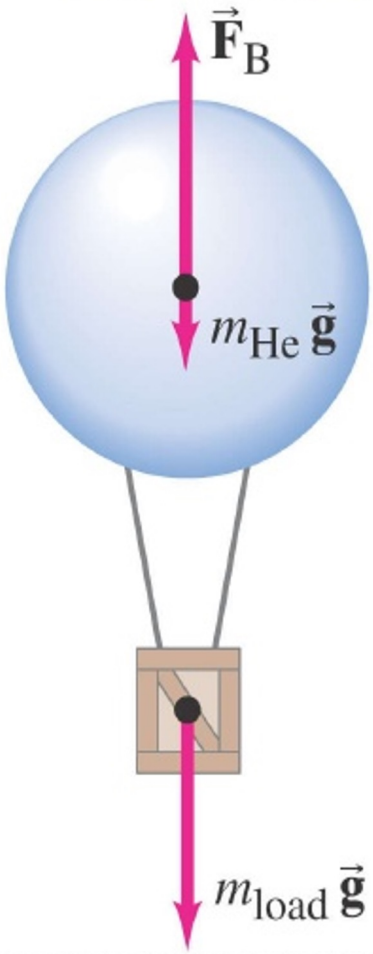
Buoyant Force Quiz Solution



- Ice is less dense than liquid H_2O, so ice floats
- The displaced water volume equals the volume of part 2 but has a mass equal to the ice cube's (part 1 + part 2) mass
- Now, look at what happens when the ice melts:
  - Its mass does not change, it is still (mass of part 1 + mass of part 2)
  - Part 1 and part 2 turn into liquid water
- But, we said above that the part 1 + part 2 mass of liquid water has the same volume as part 2.
- Therefore, the level remains the same

Application to HAB

Buoyancy and Archimedes' Principle



This principle also works in the air; this is why **hot-air** and **helium** balloons rise.

Air is mostly a mix of Nitrogen and Oxygen. Why does Helium make a balloon float?

Our HAB's ascent rate will be nearly constant – why?
Why does that HAB stop ascending at high altitude?

Back to the Online Calculator…

1 meter = 3.28 ft

http://tools.highaltitudescience.com/#

Input

Balloon Size (grams)

1500

Payload Weight (grams, 1-20000)

1060

Positive Lift (grams, 1-20000)

1600

a High Altitude Science project

Output

Required Helium (in cubic feet)

149.55362187817832

Estimated Burst Altitude (in meters)

32410

Average Ascent Rate (in meters/second)

5.690339463336963

Ascent Time (in minutes)

94.92696703720007

Log onto the website and begin to experiment with the numbers…
Our HAB's ascent rate will be nearly constant – why?

HAB Online Calculator

Engineering the HAB's Burst Altitude

- Keep the balloon size (1,500 g), and payload mass (1,060 g) fixed.
- Using the calculator, vary the lift as follows 1,000 g; 1,300 g; 1,600 g and record the following results for each lift –
  - Amount of Helium required in cubic feet
  - Average Ascent Rate in meters/sec
  - Burst Altitude in meters and in feet
  - Ascent Time in minutes
- What can we say about how changing the amount of lift effects the other results?
- To allow the cameras to capture the entire flight, we need to limit the ascent time to no more than 100 minutes.
  - What is the highest altitude we can obtain given this limitation and how much lift should we use?

HAB Online Calculator

Engineering the HAB's Burst Altitude

1 meter = 3.28 ft

http://tools.highaltitudescience.com/#

Positive Lift (g)	Required Helium (ft^3)	Ascent Rate (m/s)	Burst Altitude (m)	Burst Altitude (ft)	Ascent Time (min)
1,000 g	128 ft^3	4.74 m/s	33,460 m	109,750 ft.	118 min.
1,300 g	139 ft^3	5.26 m/s	32,910 m	107,950 ft.	104 min.
1,600 g	150 ft^3	5.69 m/s	32,410 m	106,300 ft.	95 min.
					100 mins

We'll keep the Balloon Size fixed at 1,500 g and the HAB's Payload Weight fixed at 1,060 g.

HAB Online Calculator

1 meter = 3.28 ft

Engineering the HAB's Burst Altitude

http://tools.highaltitudescience.com/#

Change in Baseline	Positive Lift (g)	Required Helium (ft^3)	Ascent Rate (m/s)	Burst Altitude (m & ft)	Ascent Time (min)
Baseline (1,060 g payload)	1,425 g	143 ft^3	5.4 m/s	32,690 m/ 107,200 ft	100 mins
3,000 g balloon	2300 g	229 ft^3	5.9 m/s	35,650 m/ 116,900 ft	100 mins
900 g payload	1400 g	137 ft^3	5.5 m/s	33,010 m/ 108,300 ft	100 mins
Longer ascent	600 g	114 ft^3	3.8 m/s	34,270 m/ 112,400 ft	150 mins
All of above	950 g	174 ft^3	4.2 m/s	37,580 m/ 123,300 ft	150 mins

HAB Online Calculator

Engineering the HAB's Burst Altitude – Home Assignment

Our baseline is a 1,500 g balloon, a 1,060 g payload, and a 105 minute maximum ascent time. Change only one of these at a time and find the best lift, maximum burst altitude, and the other parameters in the table.

1. What happens if we use a 3,000 g balloon?
2. What happens if we can lighten the HAB to 900 g?
3. What happens if we change the maximum ascent time limit to 150 minutes?
4. What happens if we change all three parameters?

What changes had the most and the least effect? Why?

HAB Online Calculator

Engineering the HAB's Burst Altitude

1 meter = 3.28 ft

http://tools.highaltitudescience.com/#

Change from Baseline	Positive Lift (g)	Required Helium (ft^3)	Ascent Rate (m/s)	Burst Altitude (m & ft)	Ascent Time (min)
3,000 g balloon					100 mins
900 g payload					100 mins
Longer ascent					150 mins
All of above					150 mins

Plan to share your results at the start of our next session.

High Altitude Balloon Carrying Amateur Radio

Balloon Physics 2 – Our HAB's Weight and Burst Altitude Revisited

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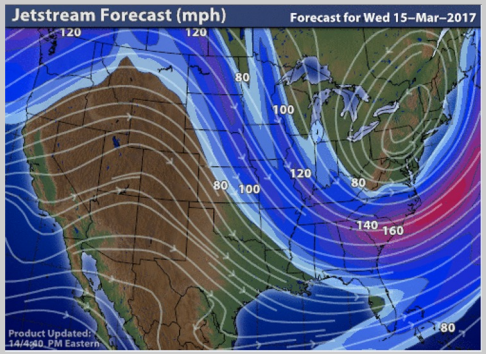
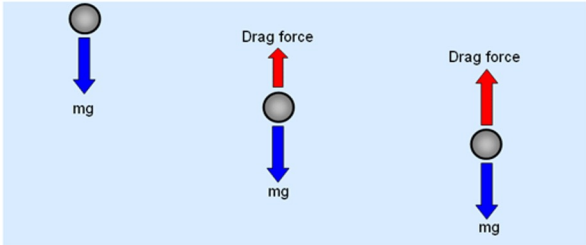


Terminal Velocity



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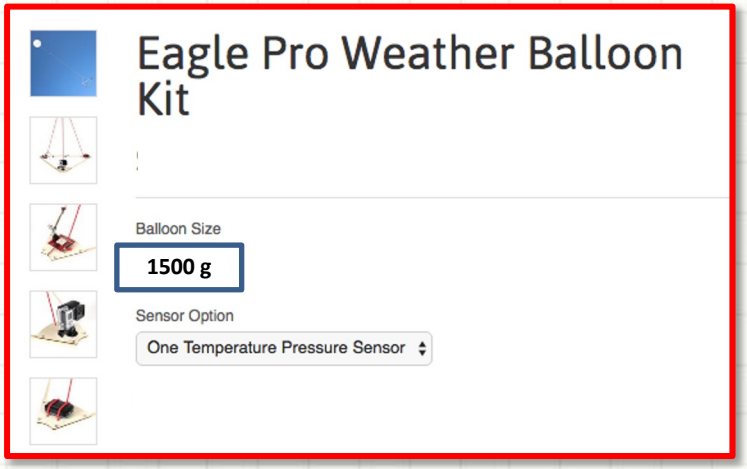

APRS

GoPro Hero 3

Its very important to have accurate weights for our HAB;s components or the results from the calculators will not be accurate.

HAB Online Calculator

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Baseline (1,060 g payload)	1,425 g	143 ft^3	5.4 m/s	32,690 m/ 107,200 ft	100 mins
3,000 g balloon	2300 g	229 ft^3	5.9 m/s	35,650 m/ 116,900 ft	100 mins
900 g payload	1400 g	137 ft^3	5.5 m/s	33,010 m/ 108,300 ft	100 mins
Longer ascent	600 g	114 ft^3	3.8 m/s	34,270 m/ 112,400 ft	150 mins
All of above	950 g	174 ft^3	4.2 m/s	37,580 m/ 123,300 ft	150 mins

How the Balloon Is Designed To Burst

Weather balloon being inflated by a leaf blower

- **Reduced pressure causes the balloon to expand.**
- Weather balloons are specially designed to be able to expand to a very large diameter. Typically they are made from latex.
- A weather balloon that starts out at 2 m (~ 6 ft) in diameter at launch can expand to a diameter of up to 10 m (over 30 ft)!
- As the balloon climbs to the edge of space it eventually expands to the point where it bursts. Our payload then falls back to earth under a parachute.

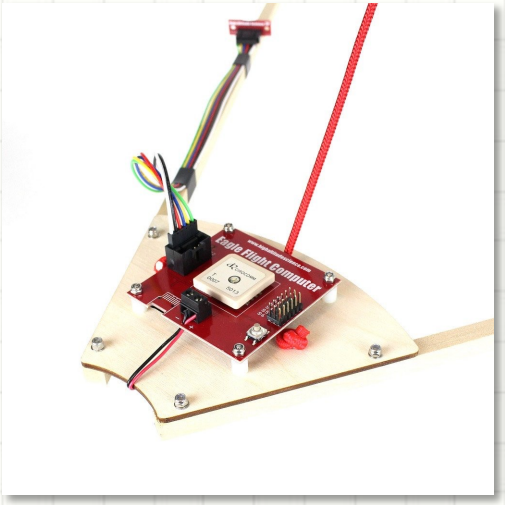
Burst Altitude Video

Balloon bursting at altitude

Balloon Bursting
YouTube Link

High Altitude Balloons

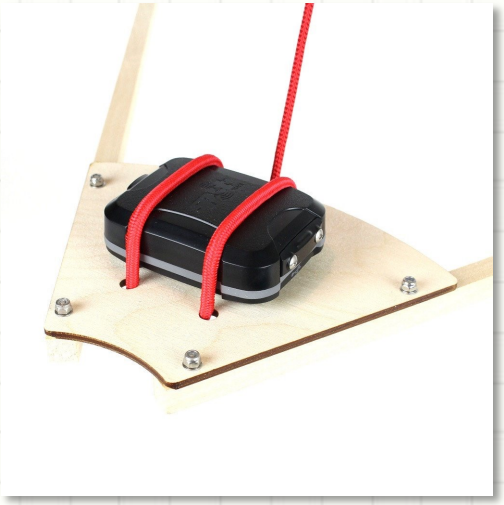
Payload Components



Flight Computer

GoPro Camera

APRS Radio Transmitter



Commercial Satellite Tracker

HAB Weight

- We need an accurate measure of our HAB platforms weight for the Balloon Calculator
- Let's weight each of the components
- Let's weight the assembled HAB
  - How does this compare to sum of the parts?
- What are the real constrains for our HAB's flight?
  - Flight time limit and what determines this?
- Back to the Balloon Calculator – lets plug in our new payload weight including the planned science experiments

Lets weight the HAB components on multiple scales and check our results

Back to the Online Calculator…

http://tools.highaltitudescience.com/#

Input

Balloon Size (grams)

1500

Payload Weight (grams, 1-20000)

1060

Positive Lift (grams, 1-20000)

1600

a High Altitude Science project

Output

Required Helium (in cubic feet)

149.55362187817832

Estimated Burst Altitude (in meters)

32410

Average Ascent Rate (in meters/second)

5.690339463336963

Ascent Time (in minutes)

94.92696703720007

Plug in our new payload weight including the planned science experiments and determine lift required for 100 min accent.

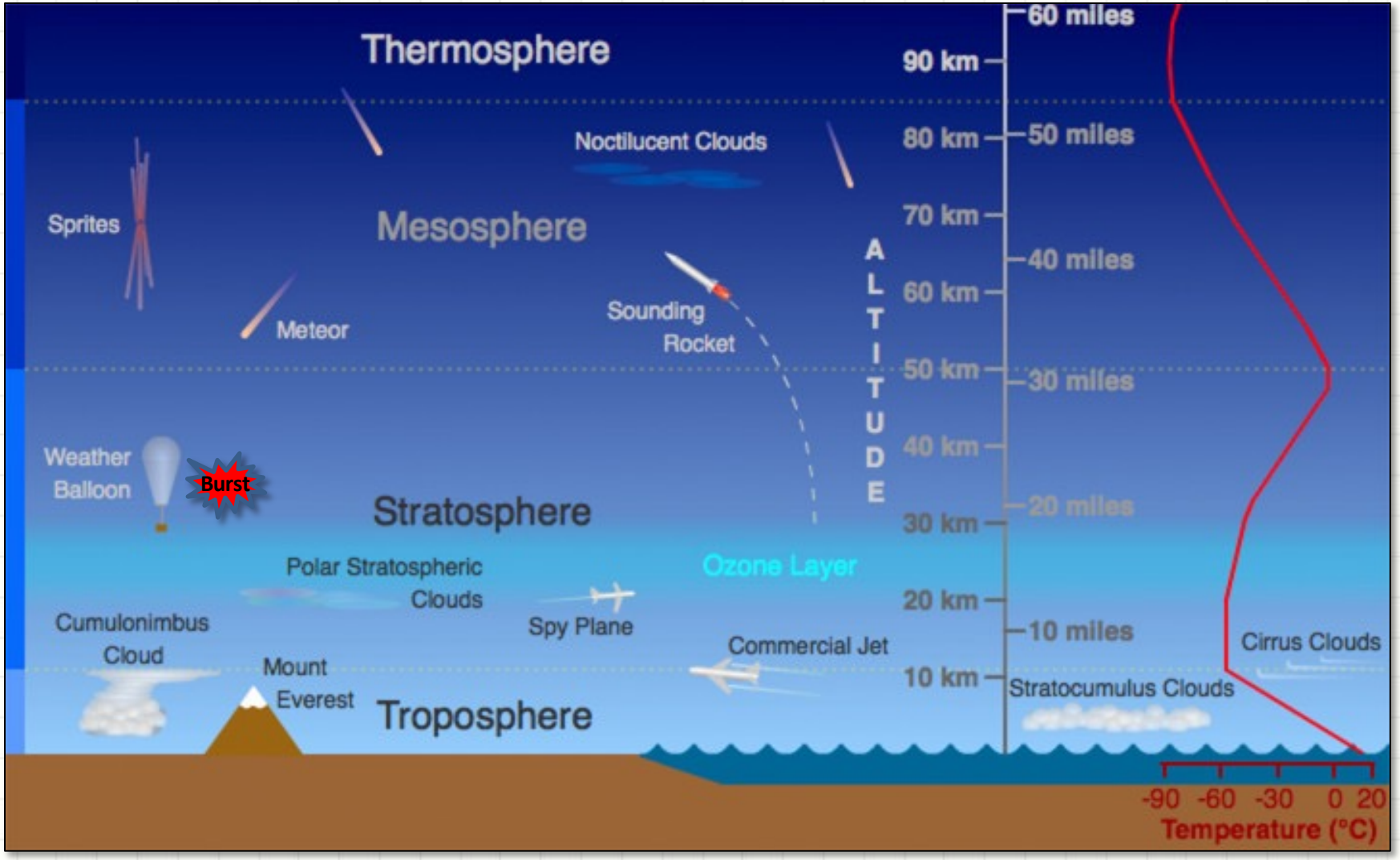
High Altitude Balloon Carrying Amateur Radio

The Atmosphere – Temperature and Pressure our HAB will encounter

Nashua Area Radio Society

N1FD

Layers of the Atmosphere

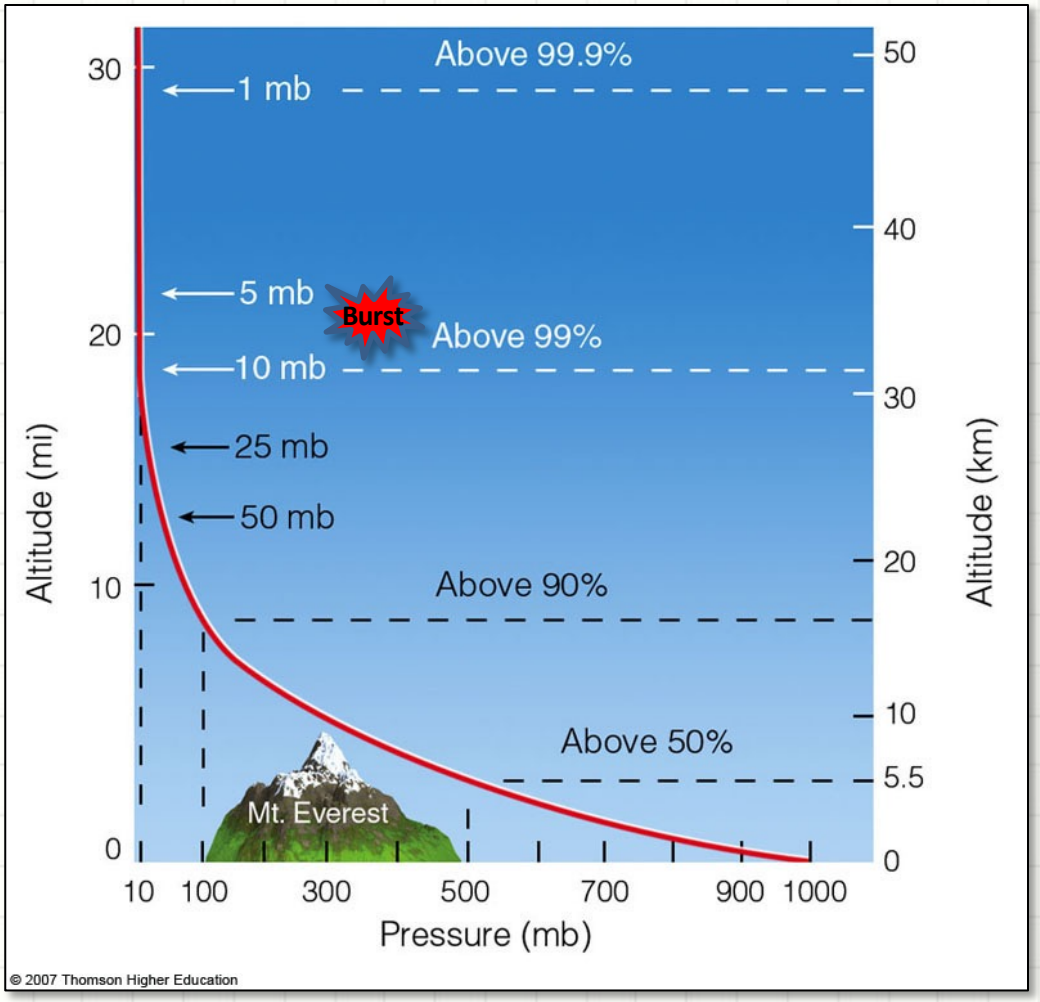


Our HAB is going to reach a maximum altitude of about 30 km, so we are exploring the lower two layers in the atmosphere

Video: Layers of the Atmosphere

[Video on YouTube]

Pressure Phenomena



- The molecules that make up the atmosphere are pulled close to the earth's surface by gravity.
- The atmosphere is concentrated at the surface and thins rapidly with altitude.
- Air pressure is a measure of the weight of the molecules above you.
- As you move higher, there are fewer molecules above you, so the air pressure is lower.
- At 10 miles up, 90% of the atmosphere is below you.

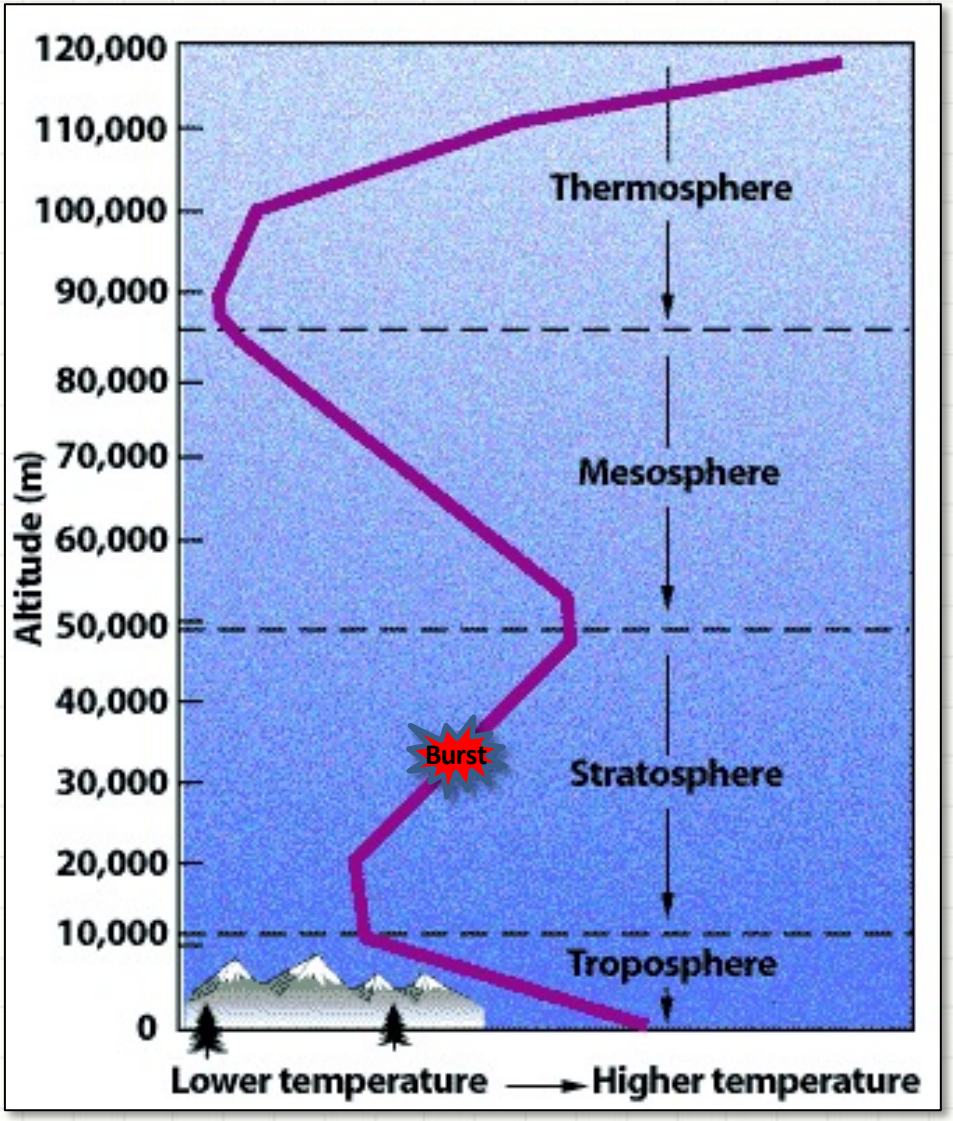
Pressure Changes in the Atmosphere

[Video on YouTube]

Atmosphere Layers

Temperature Changes

- Payload passes through distinct layers in atmosphere
- ***Troposphere*** to ~10 km
  - Temperature falls
- ***Tropopause***
  - Constant temperature for 0.2 – 0.3 km
- ***Stratosphere***
  - Temperature rises

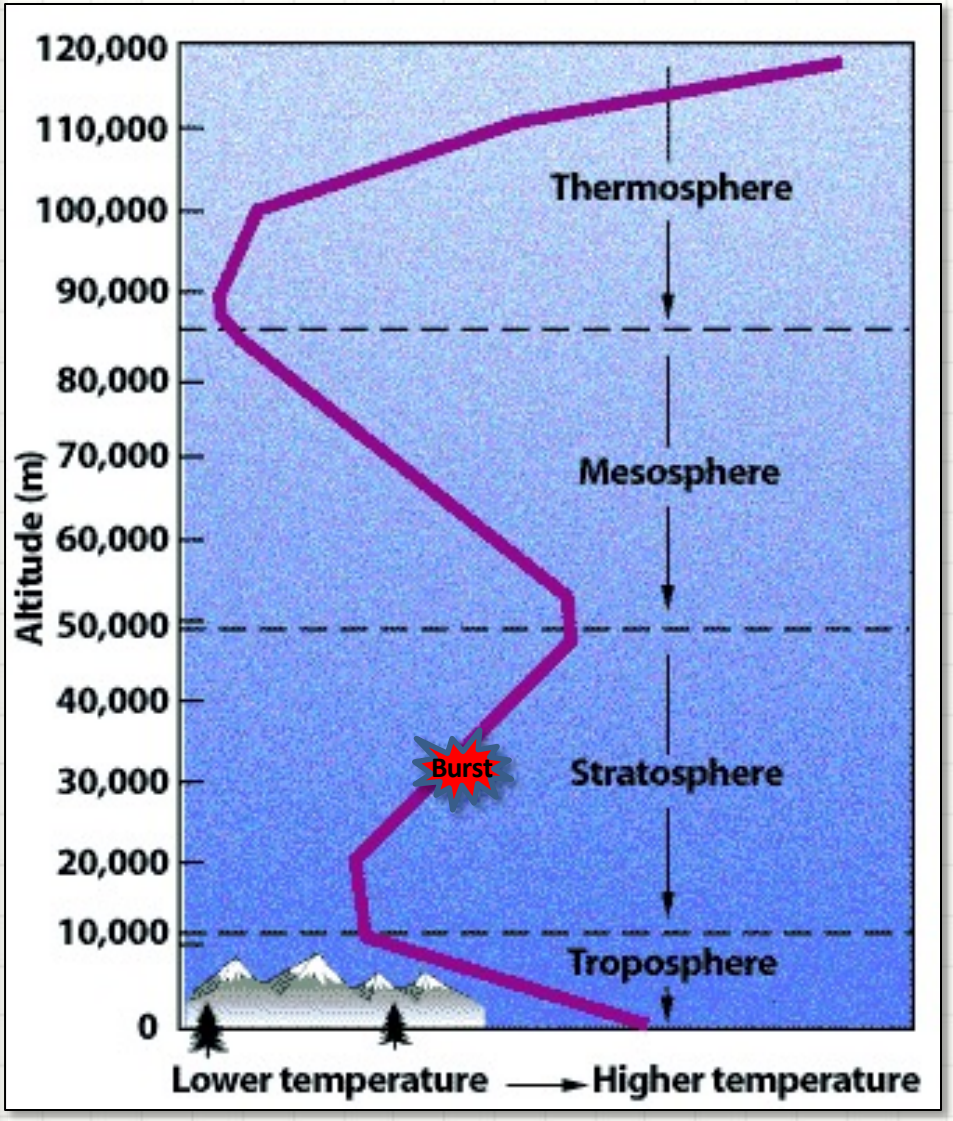


Temperature Changes in the Atmosphere

[Video on YouTube]

Atmosphere Layers

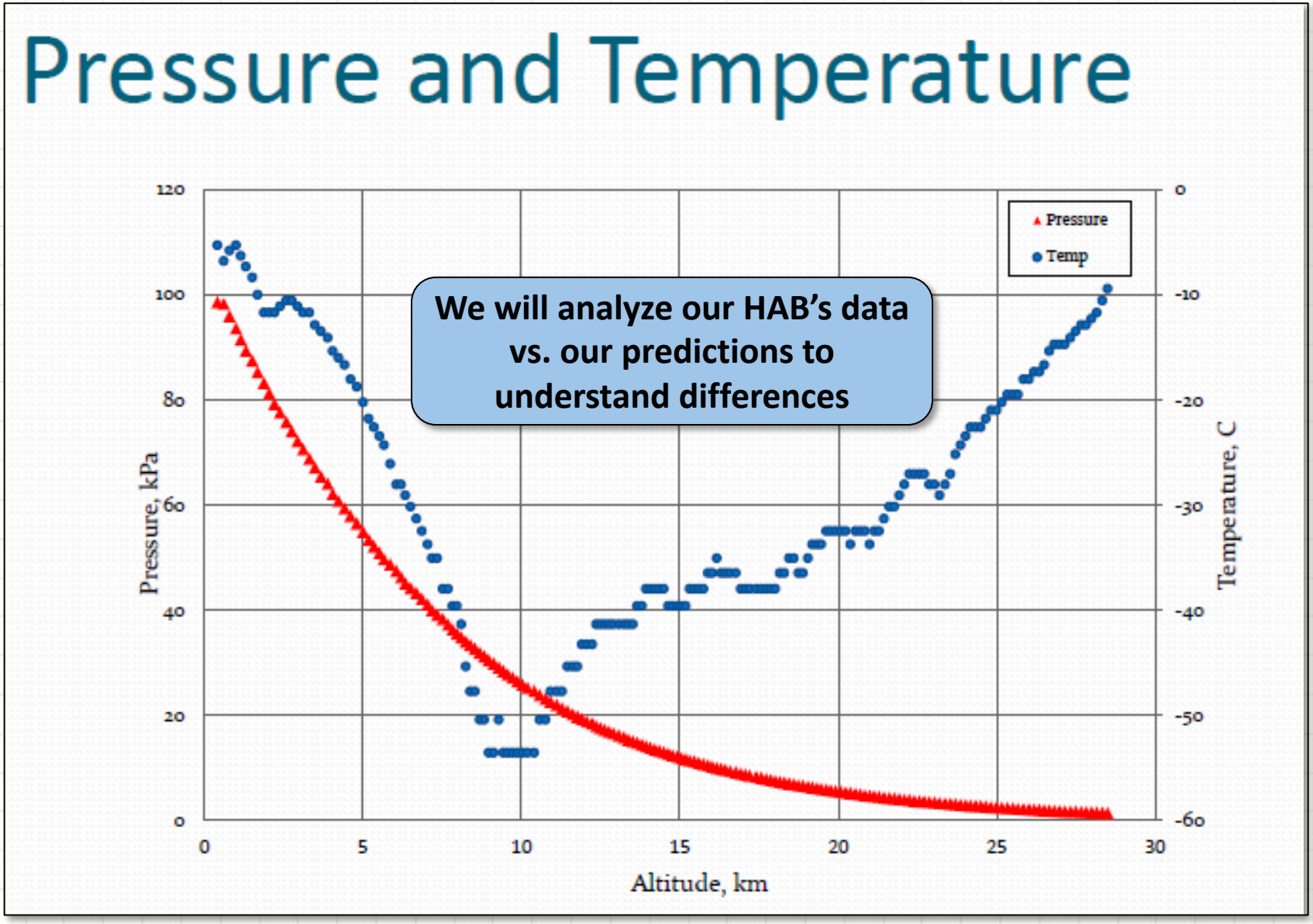
Temperature Changes and Why They Happen?



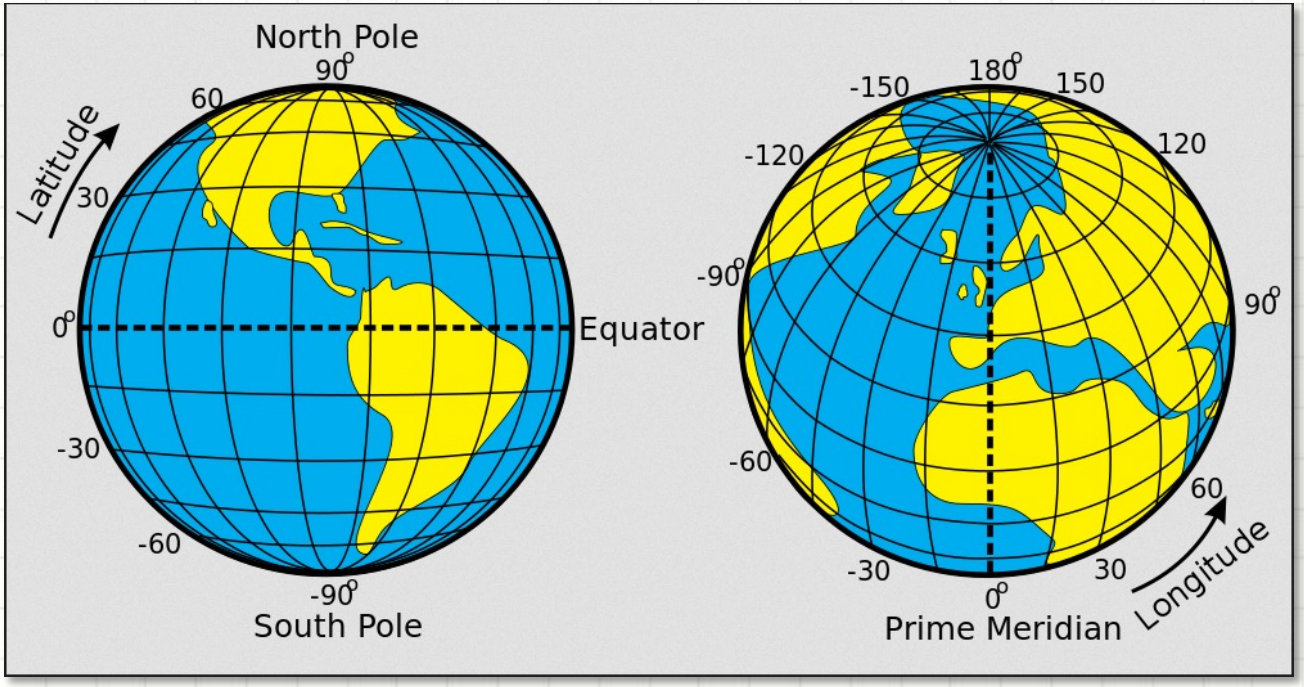
- The **troposphere** is warmer near the Earth's surface because heat from the Earth warms this air.
- As the altitude increases the number of air molecules decreases, thus the average energy decreases. The results is a decrease in air temperature with an increase of altitude.
- From 10-20 km the atmosphere is stable. This region is called the **tropopause**.
- From 20-50 km is the stratosphere. Ozone is concentrated in this layer and it absorbs UV light from the Sun.
- More light is absorbed at higher altitudes compared to the lower stratosphere, so the temperature increases.

Atmosphere Phenomena

Measurements From Another HAB Flight



Relating Latitude and Longitude to Location

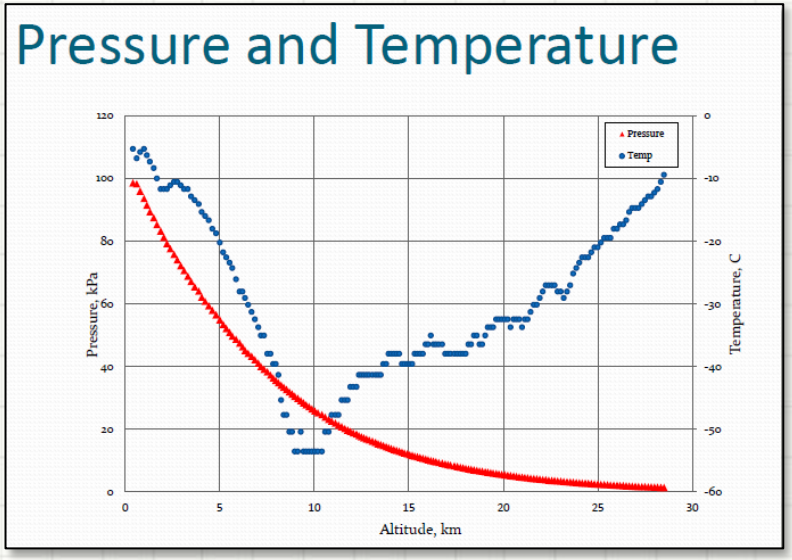


- Rules of Thumb:
  - Degrees of latitude are parallel so the distance between each degree remains almost constant.
  - But since degrees of longitude are farthest apart at the equator and converge at the poles, their distance varies greatly.
  - Each degree of latitude is **approximately 69 miles** (**111 kilometers**) apart
  - A degree of longitude is widest at the equator at **69.172 miles (111.321 km)** and gradually shrinks to zero at the poles.

Atmosphere Phenomena

What Will Our Flight Computer Record?

- The HAB's computer tells us the balloon's current location and atmospheric conditions
  - ***Position, Heading and Speed***
  - ***Altitude***
  - ***Temperature and Pressure***
  - New reading recorded every 6 seconds
  - Read data from SD card after recovery
- APRS Transmitter also sends data to ground



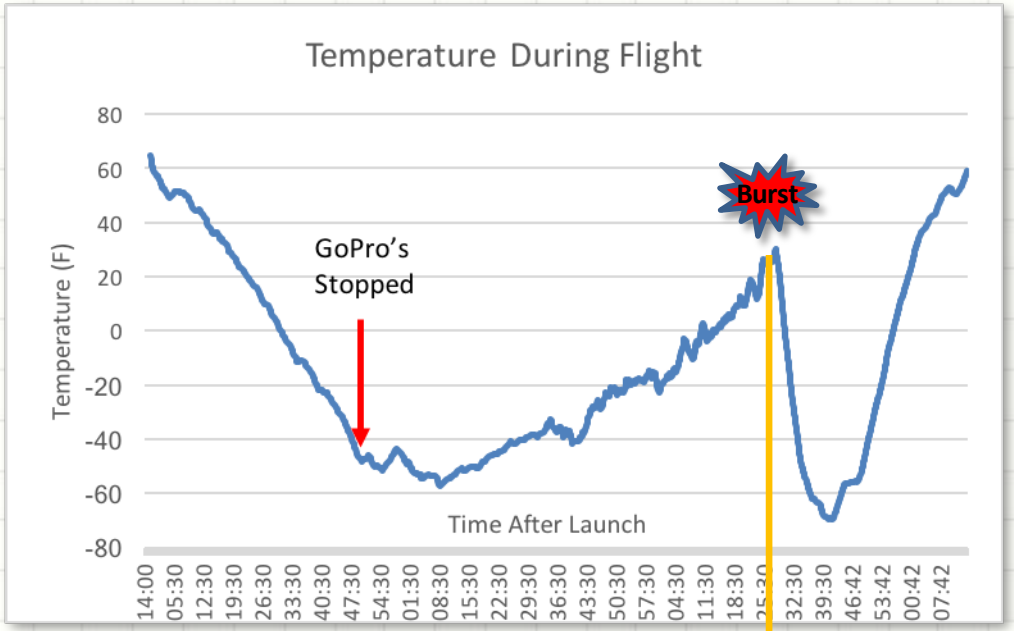
Actual HAB Flight Computer Data

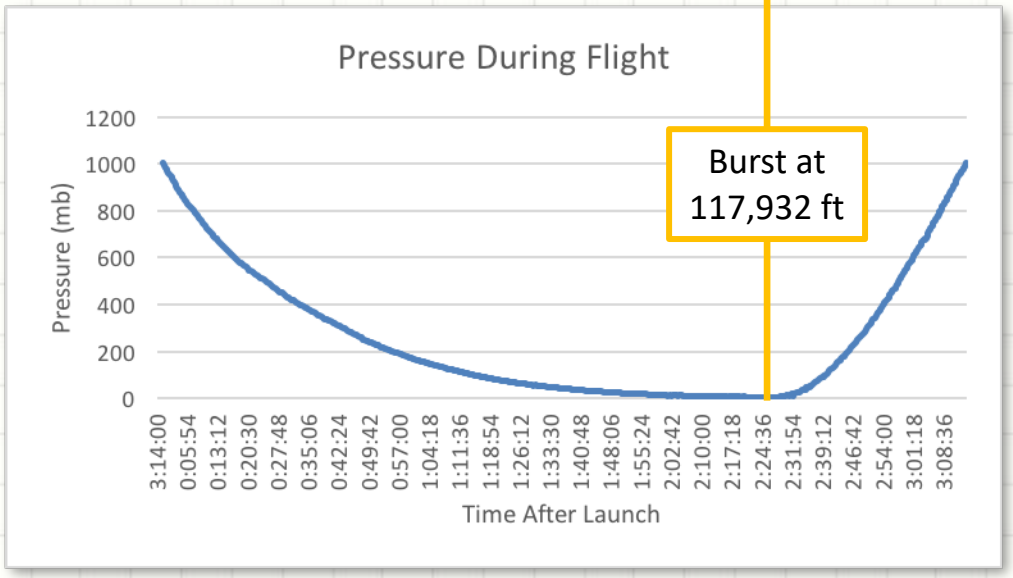
```
Date     , Time    , Latitude ,Longitude ,Head,Km/h, Alt-m ,Lock,Temp C,Pa
04/08/17,01:16:48,+042.71179,-071.59027,0148,0000,+000107,0003,+016.9,098418
04/08/17,01:16:54,+042.71178,-071.59024,0148,0000,+000110,0003,+016.0,098426
04/08/17,01:17:00,+042.71177,-071.59025,0148,0000,+000108,0003,+015.3,098436
04/08/17,01:17:06,+042.71176,-071.59025,0148,0000,+000107,0003,+014.4,098441
```

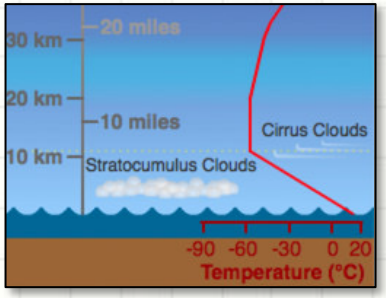
We will compare HAB flight data to our predictions to see how well they match and we will analyze and explain any differences.

HAB-2 Atmospheric Measurements

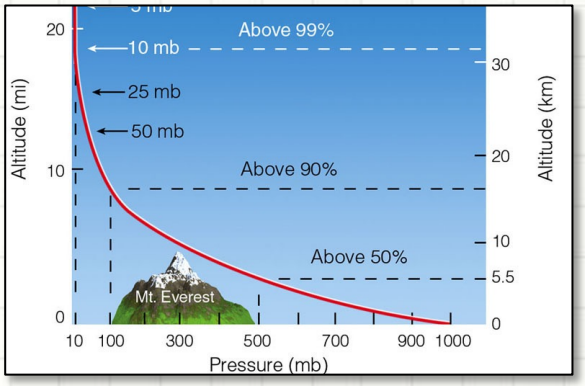
Temperature and Pressure







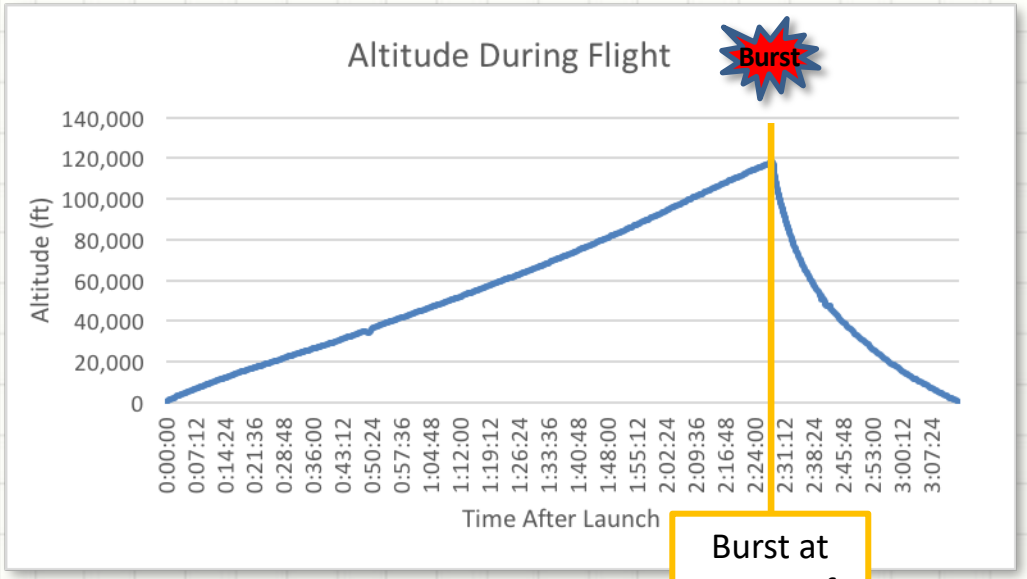
- Very cold temperatures on ascent (-57°F) & descent (-70°F)
- Cameras shutoff at around 40,000 ft due to low temperature
- Shape of temperature changes was as expected



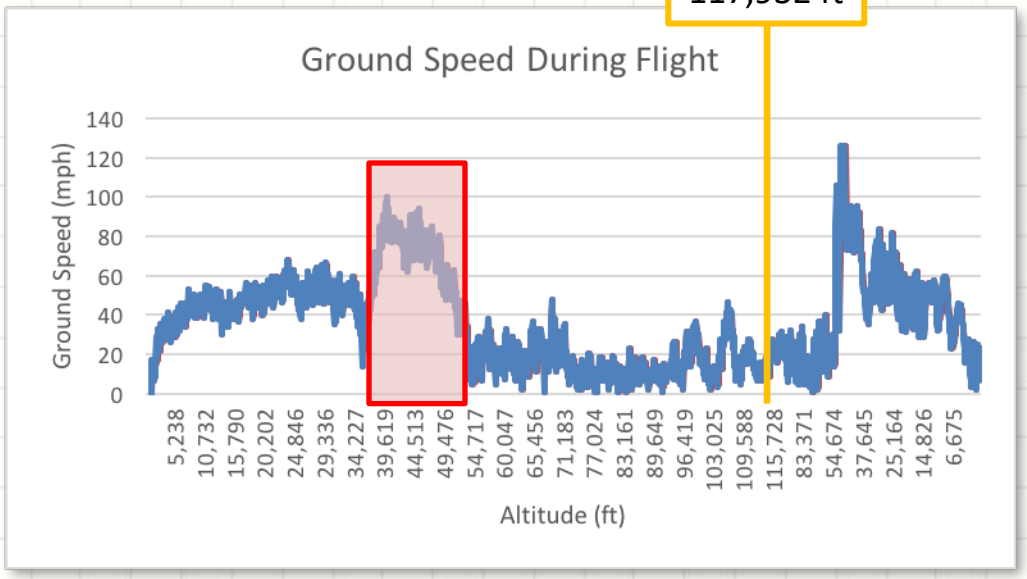
- Measured pressure

HAB-2 Speed Measurements

Ground and Descent Speed



Burst at 117,932 ft



- Ascent rate did not change much between launch and burst
- Jetstream winds increased ground speed significantly
  - ~35,000 – 50,000 ft
  - Max of ~100 mph!
- Not enough air above 50,000 ft to move HAB-2 along ground
- Descent after burst was very rapid until about 50,000 ft

Date	Time (UTC)	Time After Launch	Ground Speed (mph)	Altitude (ft)	Ascent/ Descent Rate (mph)	Notes
10/28/17	18:21:54	3:13:24	25	954	-12	
10/28/17	18:22:00	3:13:30	22	859	-11	500 AGL
10/28/17	18:22:06	3:13:36	7	768	-10	
10/28/17	18:22:12	3:13:42	7	666	-12	
10/28/17	18:22:18	3:13:48	15	567	-11	200 ft AGL
10/28/17	18:22:24	3:13:54	23	469	-11	
10/28/17	18:22:30	3:14:00	19	351	-13	Touchdown!

- Parachute descent rate was about 12 mph at landing
  - About what we expected

High Altitude Balloon Carrying Amateur Radio

Descent through the Atmosphere – Parachute operation

Nashua Area Radio Society

N1FD

Everything Falls At The Same Rate

Movie: Misconceptions About Falling Objects

Danger, Falling Objects!

Movie Explaining the Effect of Air Resistance

The air drag force is what prevents objects (like a feather and coin) from falling at the same rate when dropped from rest

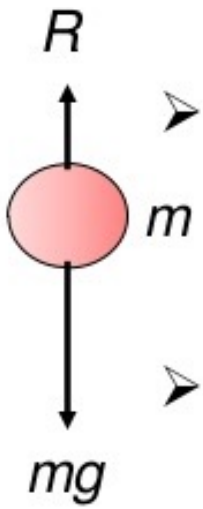
Physics in a Very Large Vacuum Chamber

Movie showing the ball/feather experiment

The Air Drag Force

** Air Resistance (drag force)

- It's the friction force on an object moving through air (or a fluid)



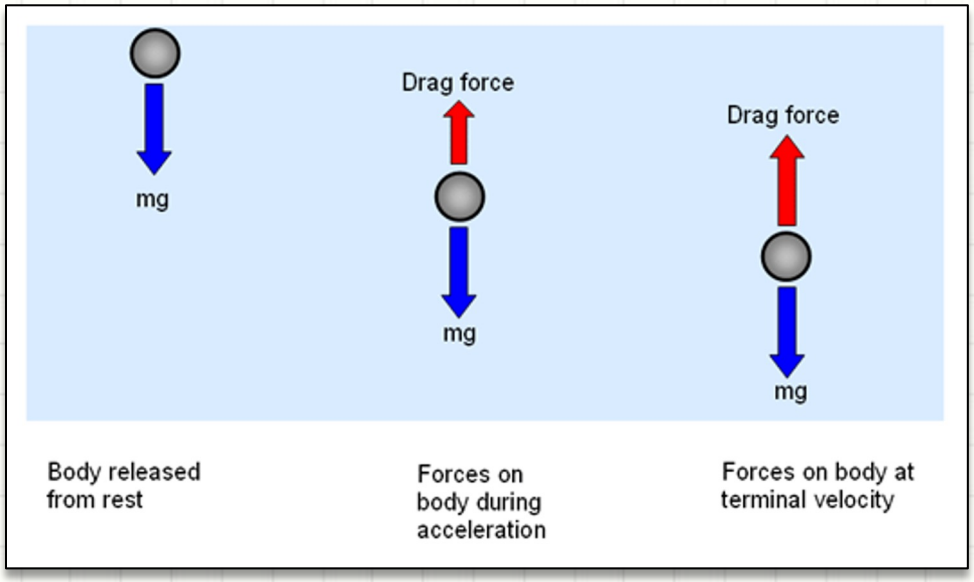
- Although we often ignore air resistance (***R)***, it is usually significant in real life.

- ***R*** depends on:
  - Speed (directly proportional to v^2).
  - cross-sectional area
  - air density
  - other factors like shape

Terminal Velocity

Force Diagram

Drag force eventually balances force of gravity



- Occurs when forces *(e.g. drag and gravity)* on balloon exactly balance
  - No acceleration
- Air pressure and temperature varies with balloon altitude
  - Air density varies as a result too
- Terminal velocity depends on mass, area of the parachute, and the density of the air

Understand the physics of terminal velocity and understand how to calculate it from our models

Terminal Velocity

Drag Force on Balloon

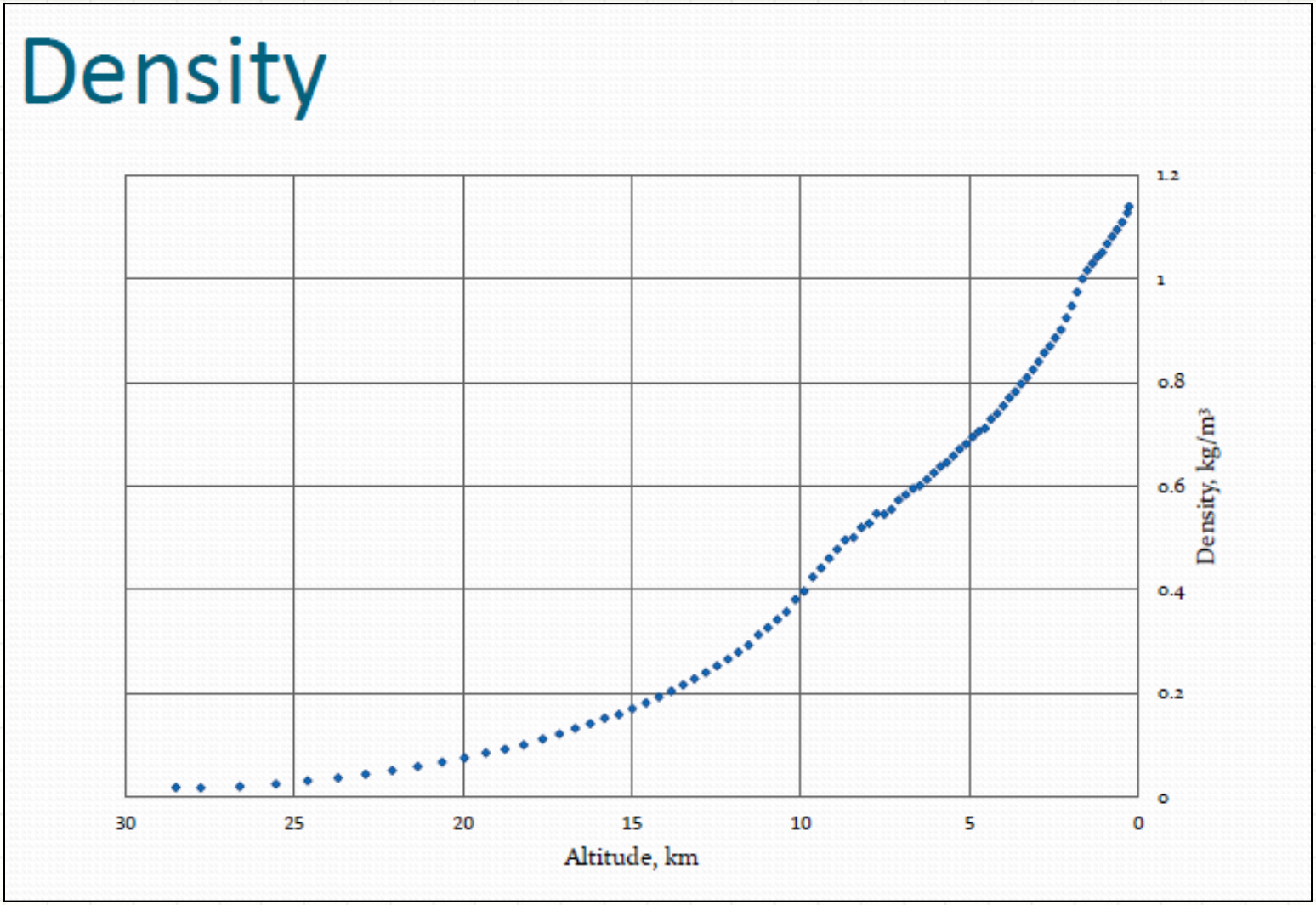
$$F_D = \frac{1}{2}\rho C A v^2$$

Easy To Determine	Harder To Determine

• Drag Coefficient (C)
  ○ Usually 0.5 - 0.7
• Area of parachute (A)
  ○ Balloon Diameter = 1 m
  ○ Balloon Area = 0.79 m^2
	• Air density (rho) at different altitudes
	• Depends on:
	  ○ Air pressure
	  ○ Air temperature

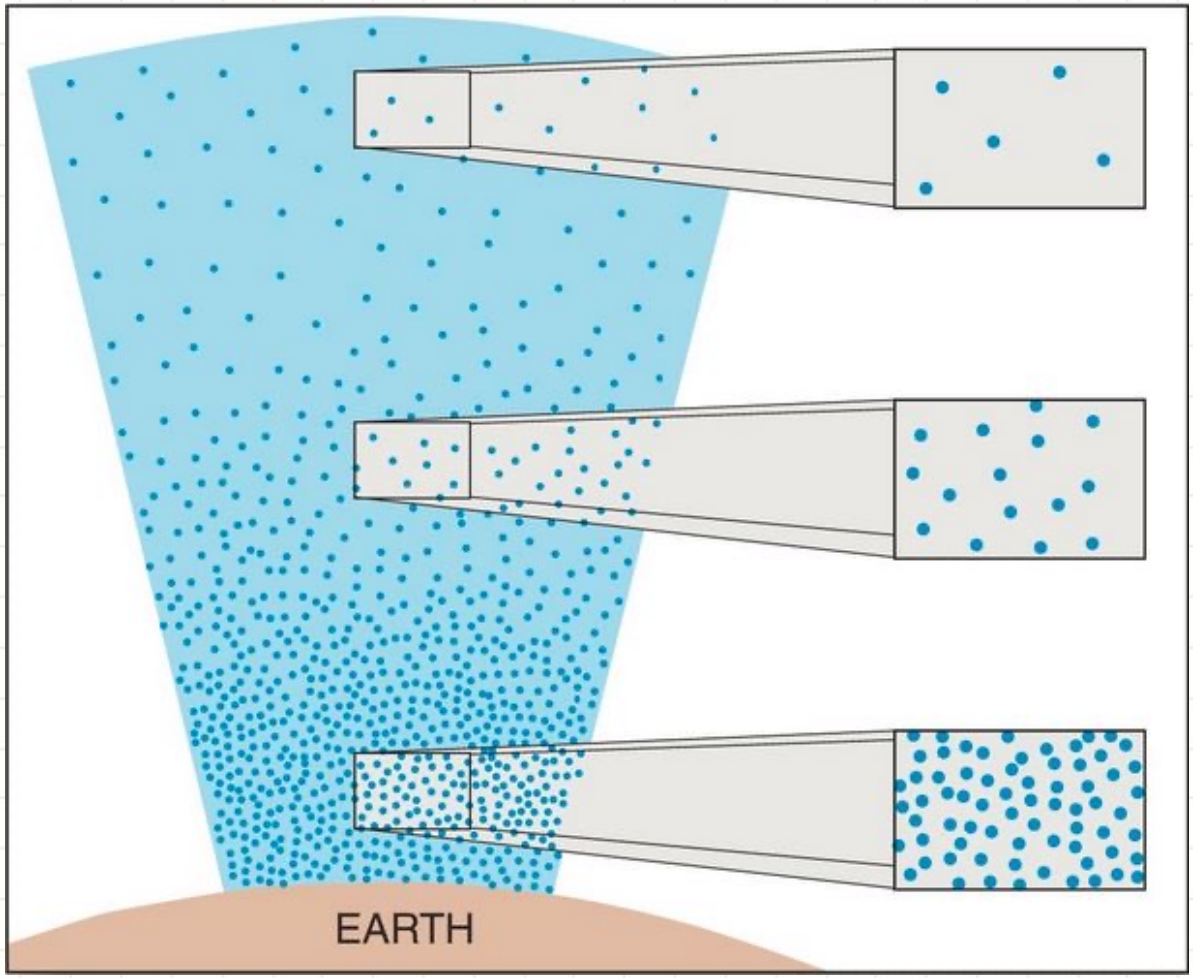
Focus on how air density varies with altitude

Air Density In The Atmosphere



Density decreases with increasing altitude because there is less atmosphere (air molecules) at higher altitudes

Another View of Air Density In the Atmosphere



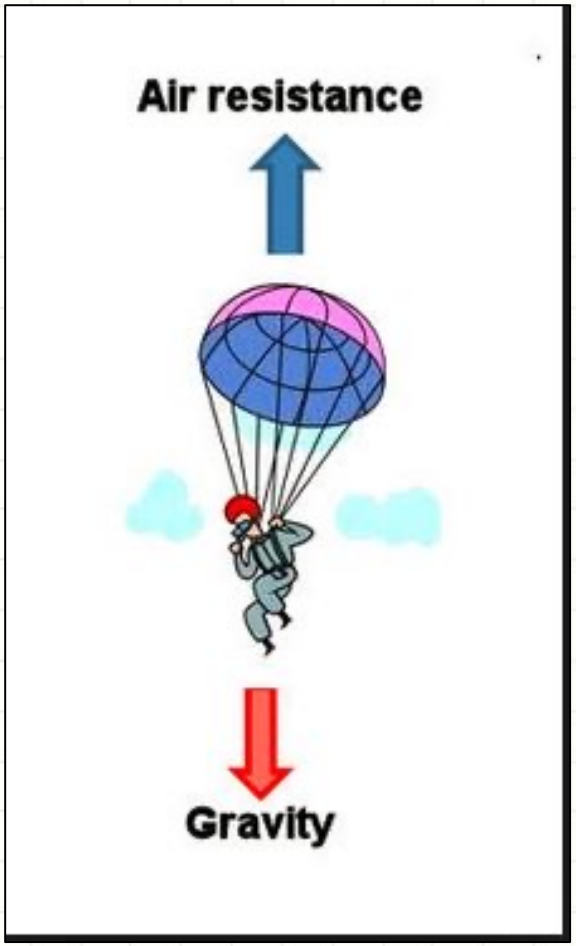
Higher Altitude

Lower Altitude

Since the air gets thicker the lower you go, what can we put on our balloon to help slow it down as it gets closer to the Earth's surface?

Uses of Parachutes

Space shuttle returning from a mission. It uses a parachute to help slow it down while on the runway



A skydiver uses a parachute to help him maintain a constant speed as he falls

Parachute Performance

- Need to keep terminal velocity to a maximum of 7 m/s or ~ 16 mph
  - Depends on parachute size (ours' is 1 m or ~ 36” in diameter)
  - Depends on payload weight
- Need to keep combination of ascent plus decent time to a total of less that 2-1/2 hours (150 minutes)
- Drag Table for our Parachute (assuming max. altitude of 100,000 ft)

Payload Weight	Landing Speed	Decent Time from 100,000 ft
0.6 kg / 1.3 lb	4.8 m/s ~ 11 mph	50 minutes
0.8 kg / 1.8 lb	5.5 m/s ~ 12 mph	44 minutes
1.0 kg / 2.2 lb	6.2 m/s ~ 14 mph	39 minutes
1.2 kg / 2.6 lb	6.8 m/s ~ 15 mph	36 minutes
1.3 kg / 2.9 lb	7.1 m/s ~ 16 mph	35 minutes
1.4 kg / 3.1 lb	7.3 m/s ~ 16.3 mph	33 minutes

High Altitude Balloon Carrying Amateur Radio

Predicting our HAB's Flight Path – Its mostly about the Jetstream

Nashua Area Radio Society

N1FD

Predicting the HAB's Flight Path

Burst Calculator

Required Helium (in cubic feet)

124.38834896598486

Estimated Burst Altitude (in meters)

31290

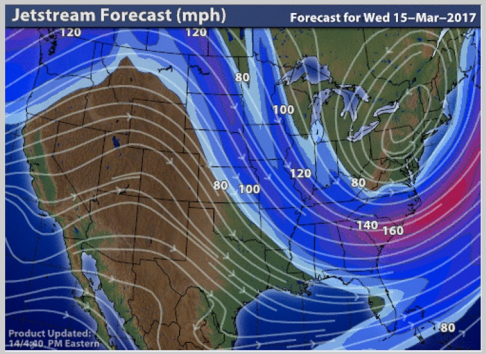
Average Ascent Rate (in meters/second)

5.240119821856709

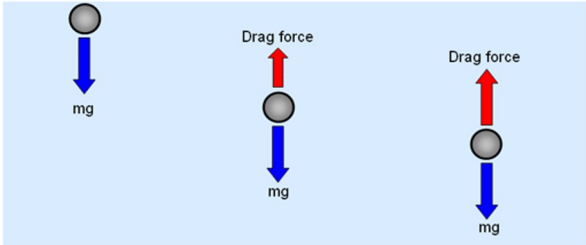
Ascent Time (in minutes)

99.52062504845914

Jetstream

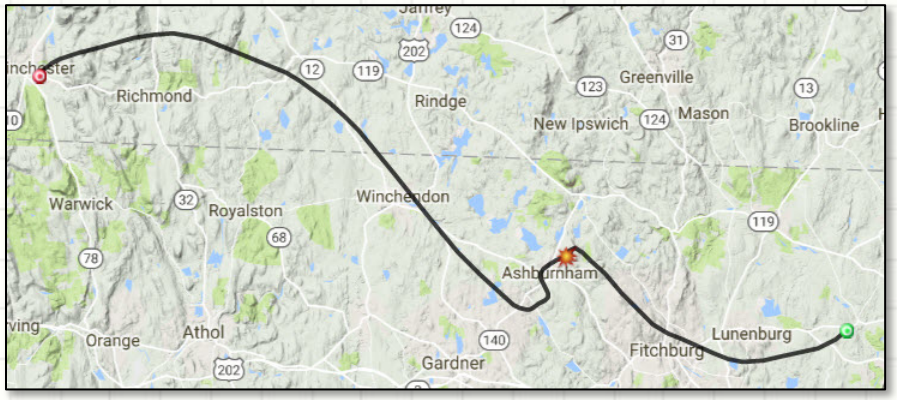


Terminal Velocity



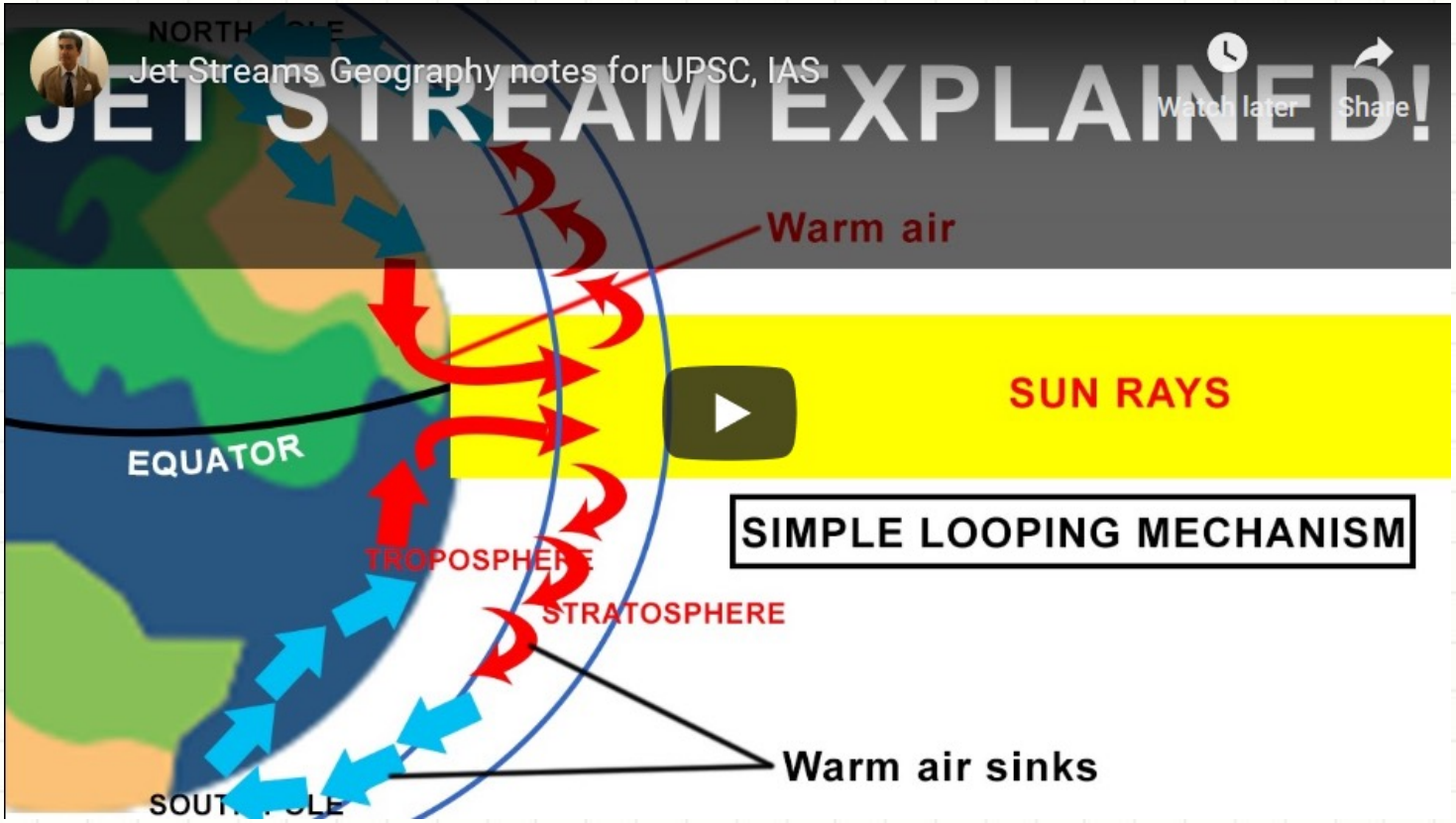
Flight Path Predictions

HAB Path Prediction Dependencies



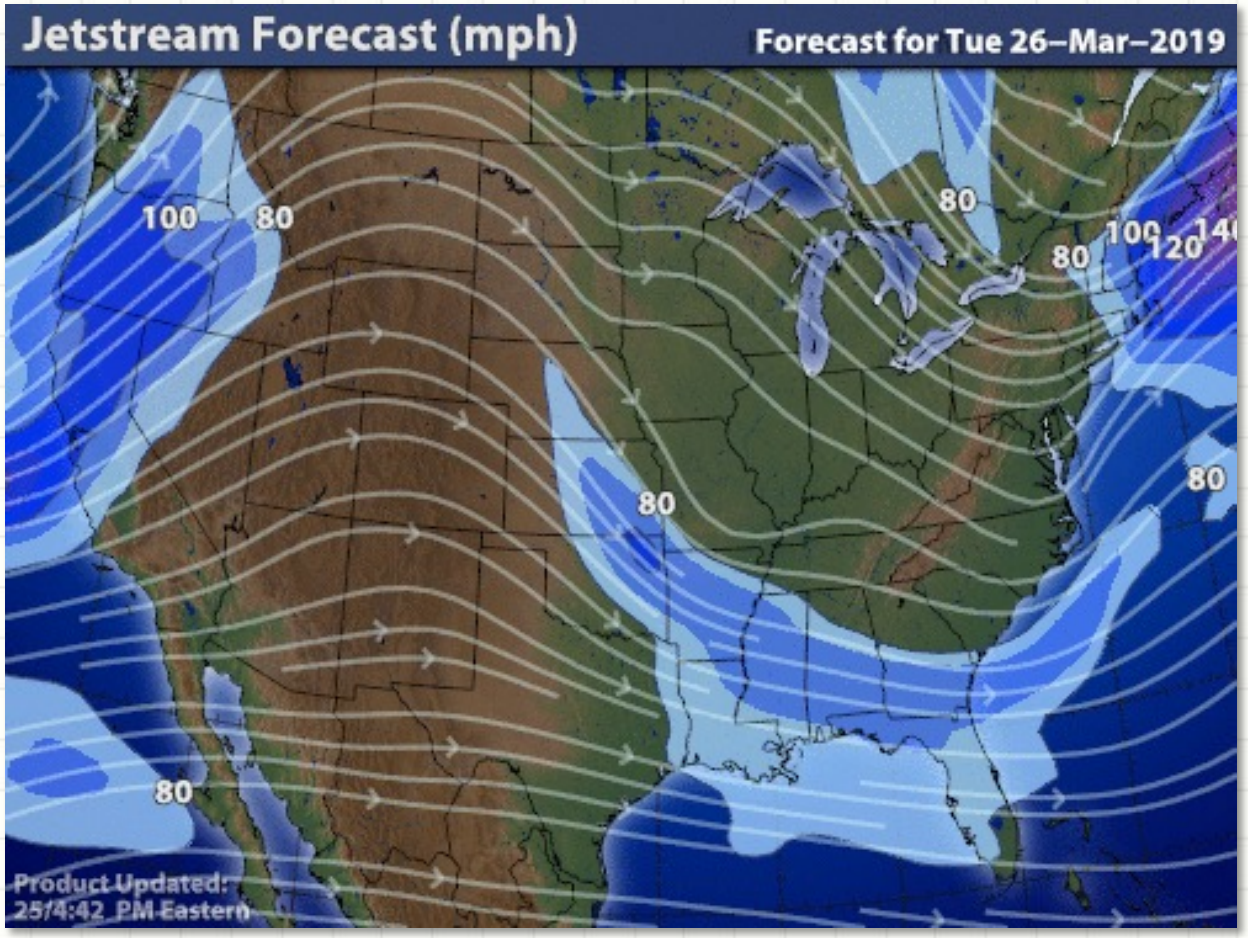
- ✓ Use estimates of ascent & descent times/speeds from Balloon Calculator and Parachute Table
- ➢ Understand the influence of the Jetstream
  - A very difficult technical problem
  - Use online resources
- ➢ Online prediction calculators and tools
  - Determine suitable starting points
  - Use tool to predict flight path, where balloon is expected to burst, and eventually land
  - Use results balloon calculator as inputs

Jetstream Explained



[Video on YouTube]

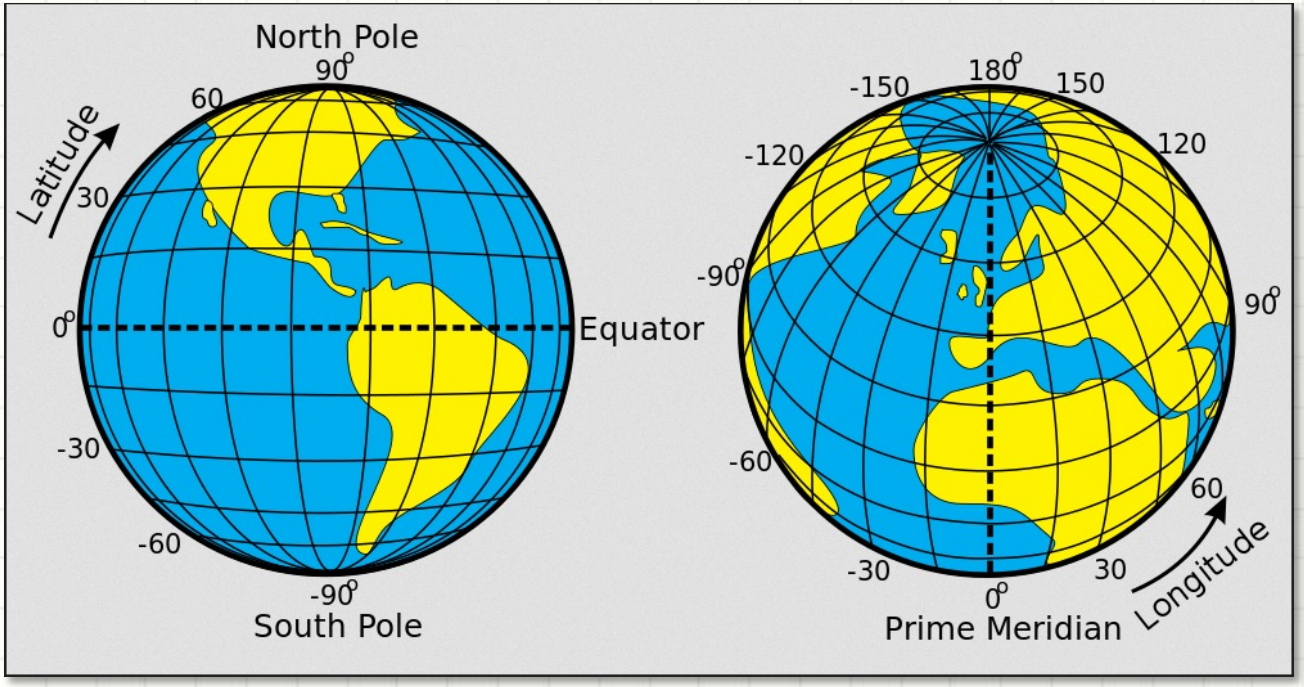
Recent Jetstream Forecast



[Current Jetstream Forecast]

Forecasting the Jetstream is difficult, so let's leave it to the experts; we'll use their tools and results

Relating Latitude and Longitude to Location



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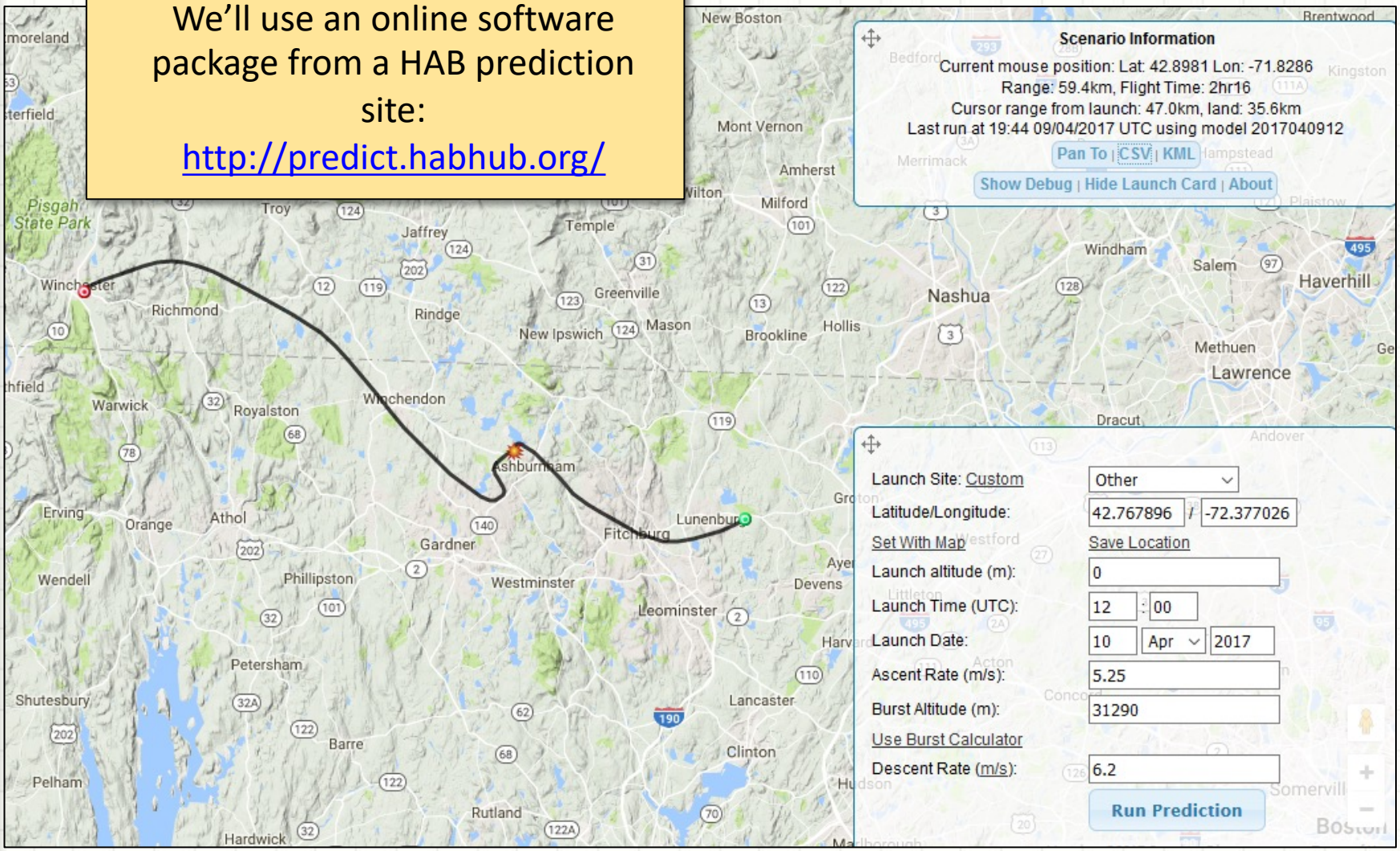
  - But since degrees of longitude are farthest apart at the equator and converge at the poles, their distance varies greatly.
  - Each degree of latitude is **approximately 69 miles** (**111 kilometers**) apart
  - A degree of longitude is widest at the equator at **69.172 miles (111.321 km)** and gradually shrinks to zero at the poles.

Flight Prediction Software

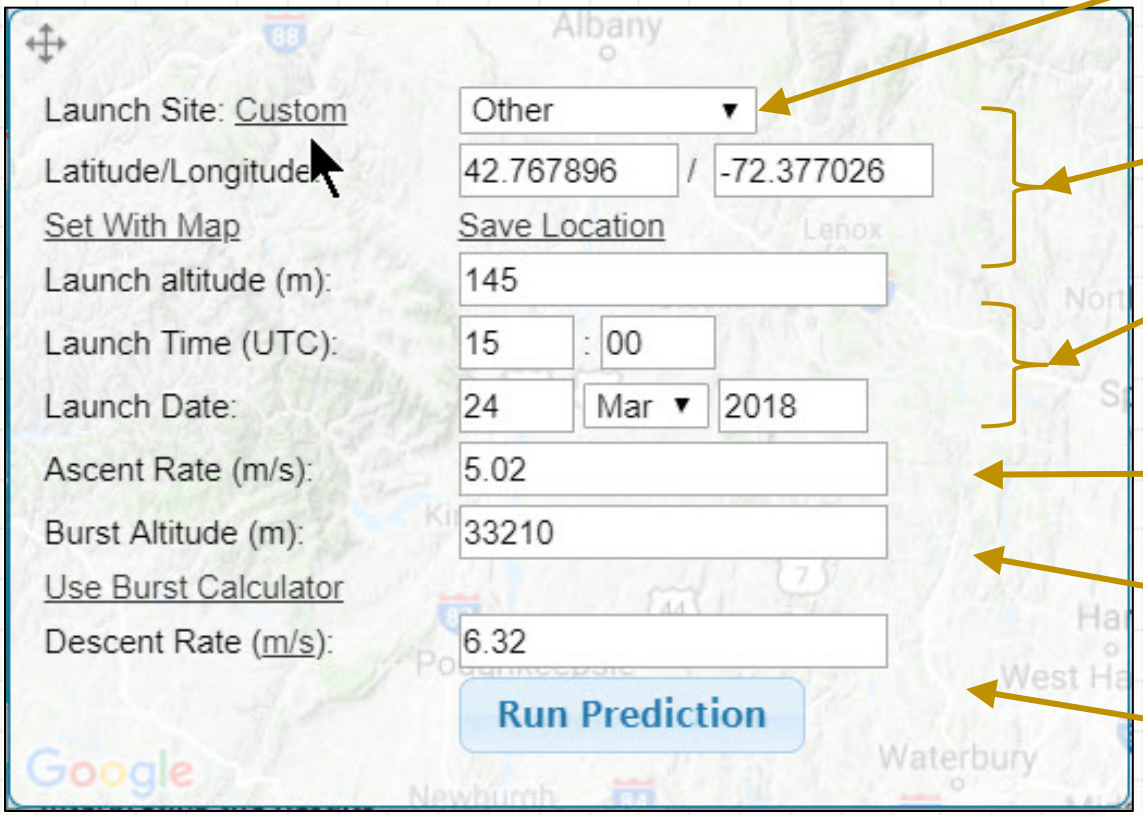
We'll use an online software package from a HAB prediction site:
http://predict.habhub.org/



Flight Prediction Inputs

We'll use an online software package from a HAB prediction site: http://predict.habhub.org/

Input Data Window



Save run, location, and results

Define launch location

Launch date and time

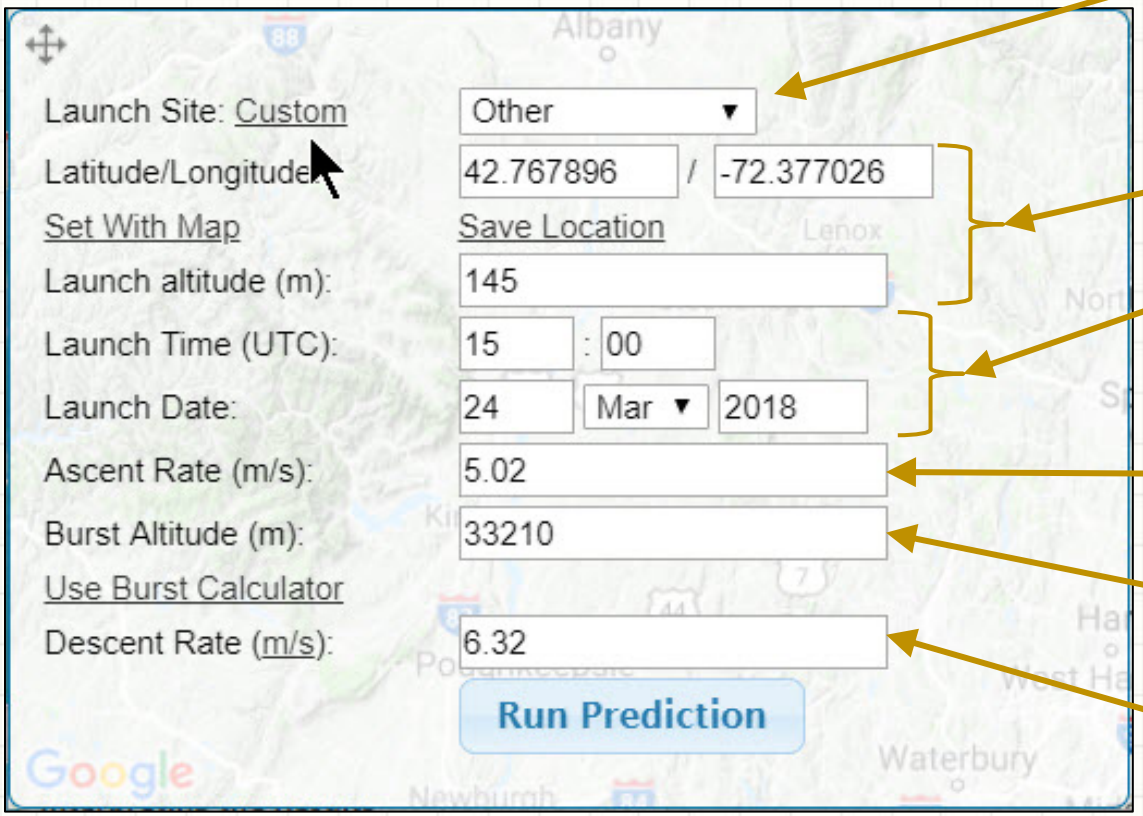
Average ascent speed

Burst altitude

Descent rate (at impact)

Flight Prediction Inputs

Input Data Window



Save run, location, and results

Define launch location

Launch date and time

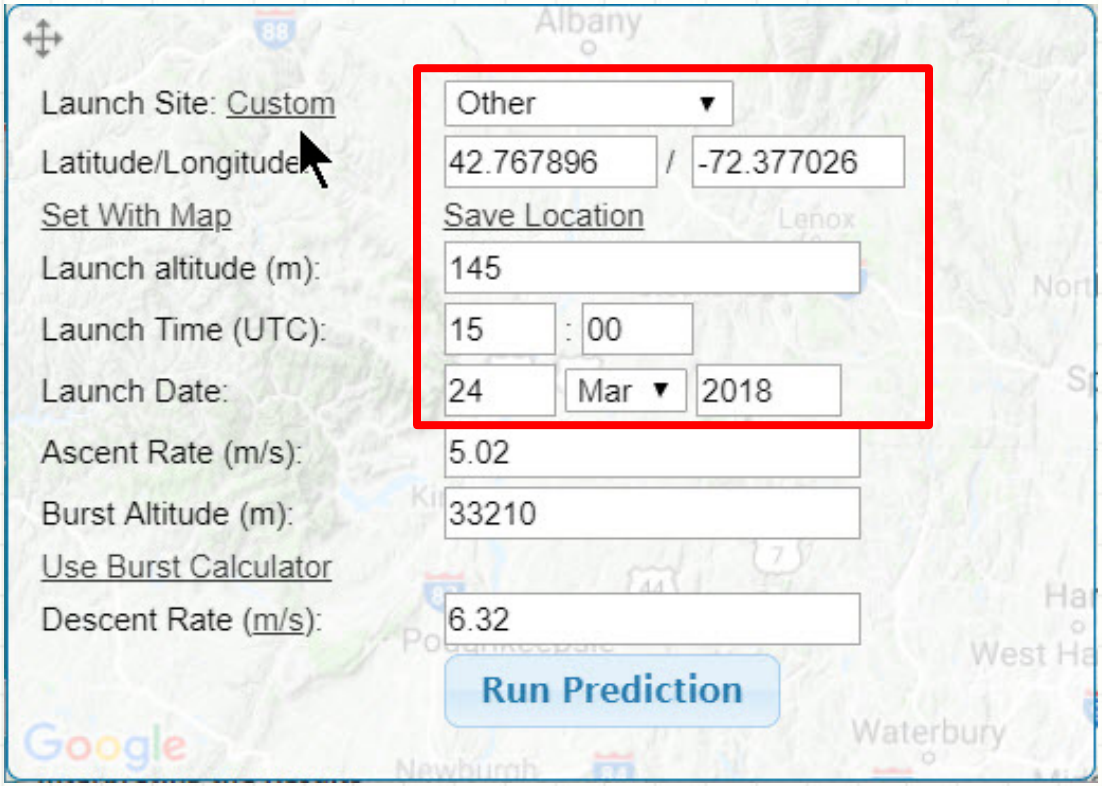
Average ascent speed

Burst altitude

Descent rate (at impact)

Launch Site: Winchester, NH elem. School: Lat = 42.767896 / Lon = -72.377026

Importance of Location and Time Inputs



- Need to specify ***when*** and ***where*** because Jetstream changes daily
- Most online tools only **accurate to within 5 days** due to changing Jetstream conditions
- Keep re-running predictions as time gets closer to be accurate

It's essential to keep re-running predictions in order to see if the predicted path and outputs stabilize as launch day approaches

HAB Flight Parameters

- Balloon Size: 1500 g
- Payload weight including parachute: 930 g
- Positive Lift: 1150 g
- Burst altitude: 33,420 m a.s.l.
  (~ 109,600 ft. or ~20.8 mi)
- Required Helium: 129 cu. ft.
- Average Ascent Rate: 5.07 m/s
- Ascent time: 110 mins
- Descent time: 41 mins
- Final descent speed: 5.92 m/s (~ 14 mph)
- Total flight time: 151 mins (2 hrs and 31 mins)

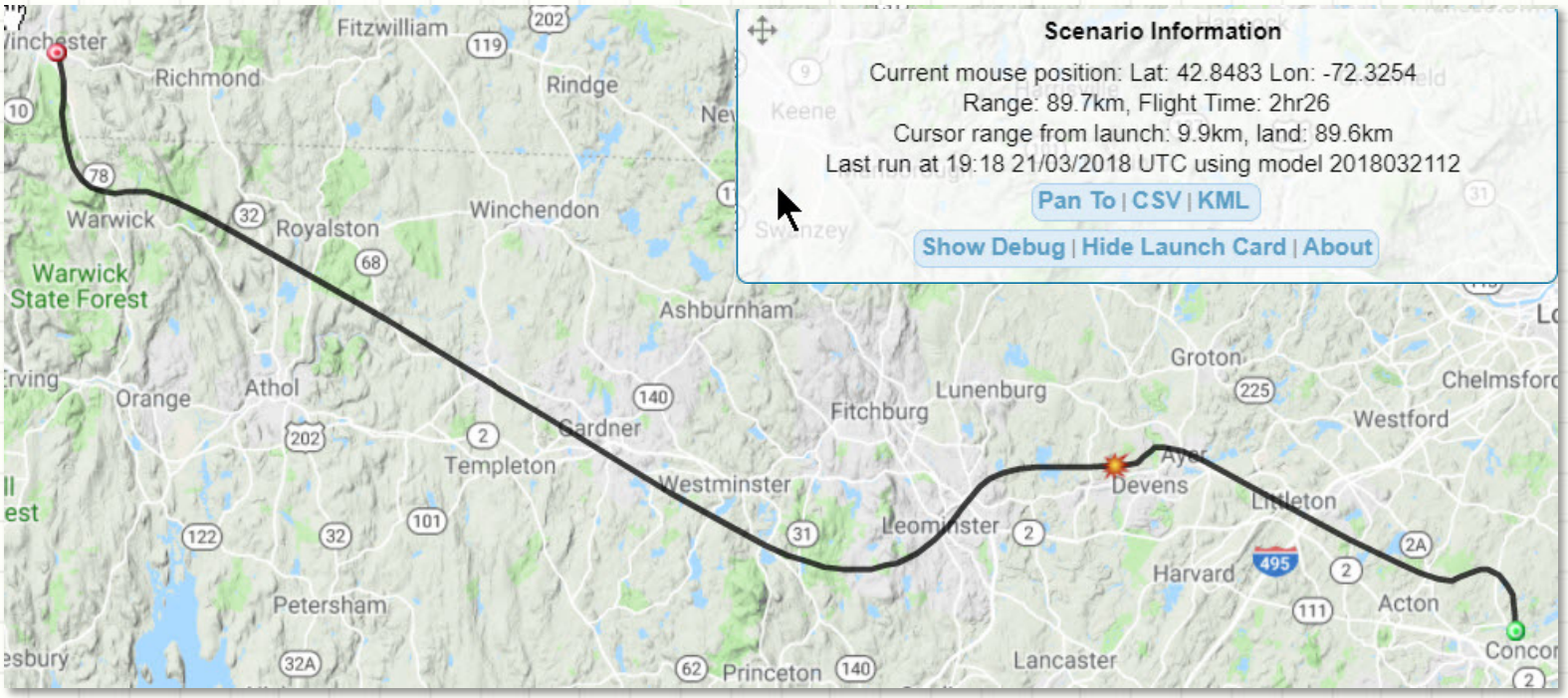
These parameters are conservative and should keep our HAB's total flight time at 2-1/2 hours and our landing speed safe.

Running the Prediction Tool

We'll use an online software package from a HAB prediction site: http://predict.habhub.org/

- Website starts you in the UK: Zoom out using mouse and move map to MA or NH
- Click ***Set With Map*** in order to use the mouse to click the balloon's starting point or use Lat/Lon coordinates
  - Winchester, NH School: **Lat/Lon = 42.767896, -72.377026 (alt. 145 m)**
  - Bennington, VT School: **Lat/Lon = 42.906806, -73.18856 (alt. 258 m)**
- Our ***Launch Altitude*** in Winchester, NH would be 145 m (from web)
- Select a ***Launch Time*** *(UTC)* and ***Launch Date***
  - Look UTC up online in case your unfamiliar
  - Right now, 11 am ET would be 15:00 UTC
- Use results from High Altitude Science Balloon Calculator and feed into ***Ascent Rate*** and ***Burst Altitude***
- Use the parachute chart to estimate the ***Descent Rate***
- ***Run the Prediction!***

Interpreting the Results



- Move your mouse along the path and observe how the values in the image above will change.
  - Note the flight time. Is this in line with maximum flight time? If not, what can you vary to change it?
- Click on the ***CSV*** button. This will export the flight path as an Excel file.

Working With the Exported File

- The Excel file will have **four columns**
  - **(A) Raw Time (in seconds)**
  - **(B) Longitude (in degrees)**
  - **(C) Latitude (in degrees)**
  - **(D) Altitude (in meters)**
- The time column **(A)** the absolute time in seconds. These number change by the same amount for each row.
- Create a new column **(E)**, that begins with 0 and each successive entry subtracts the raw ***starting*** time from the raw ***current*** time and divides the result by 60 to get minutes after launch
- Create a new column **(F)**, which converts the altitude column **(D)** to feet (1 meter = 3.28 ft).
- Label all of the columns. What's the maximum flight time?

Original Time Column

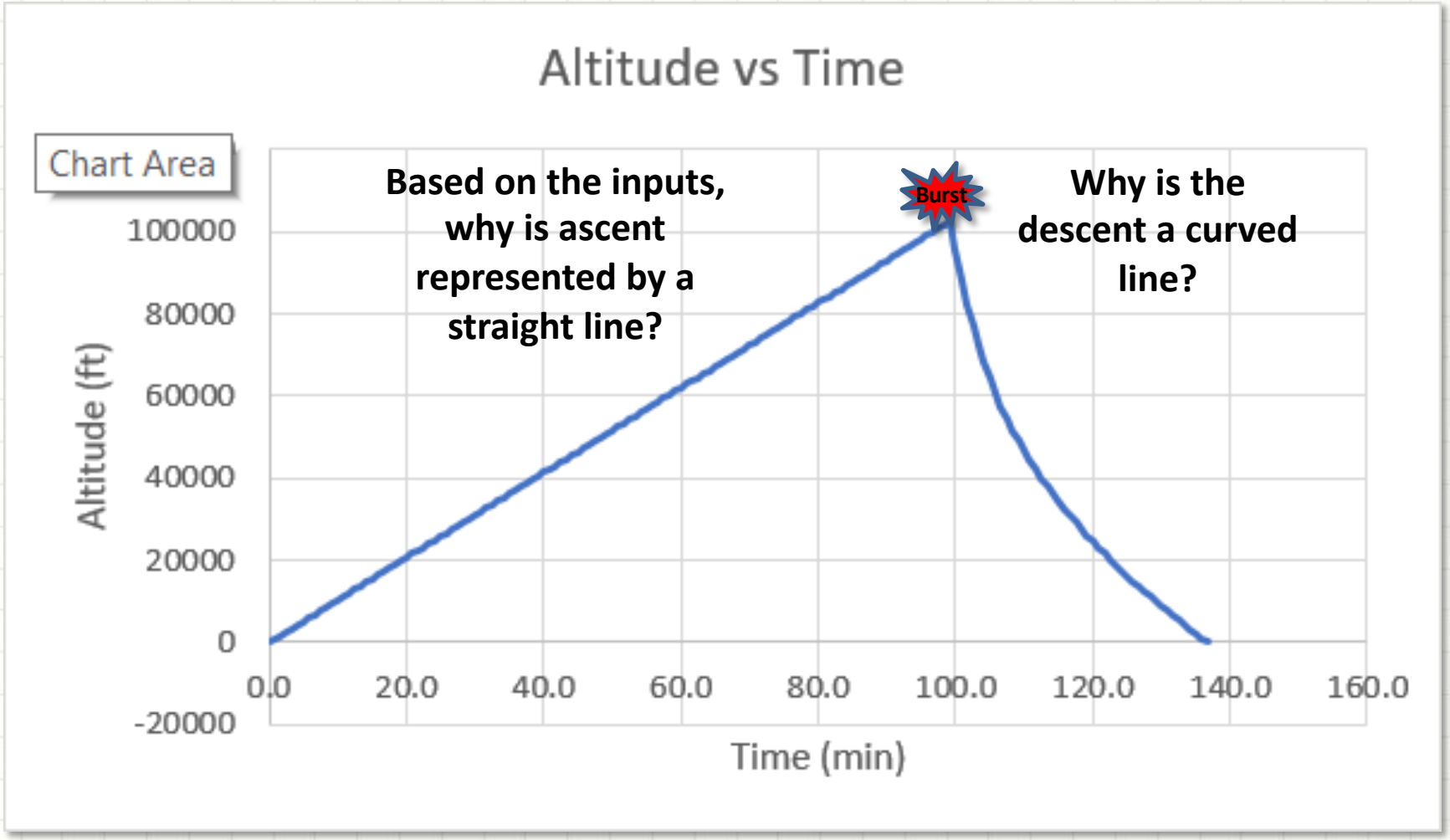
New Elapsed Time Column

New Altitude Column

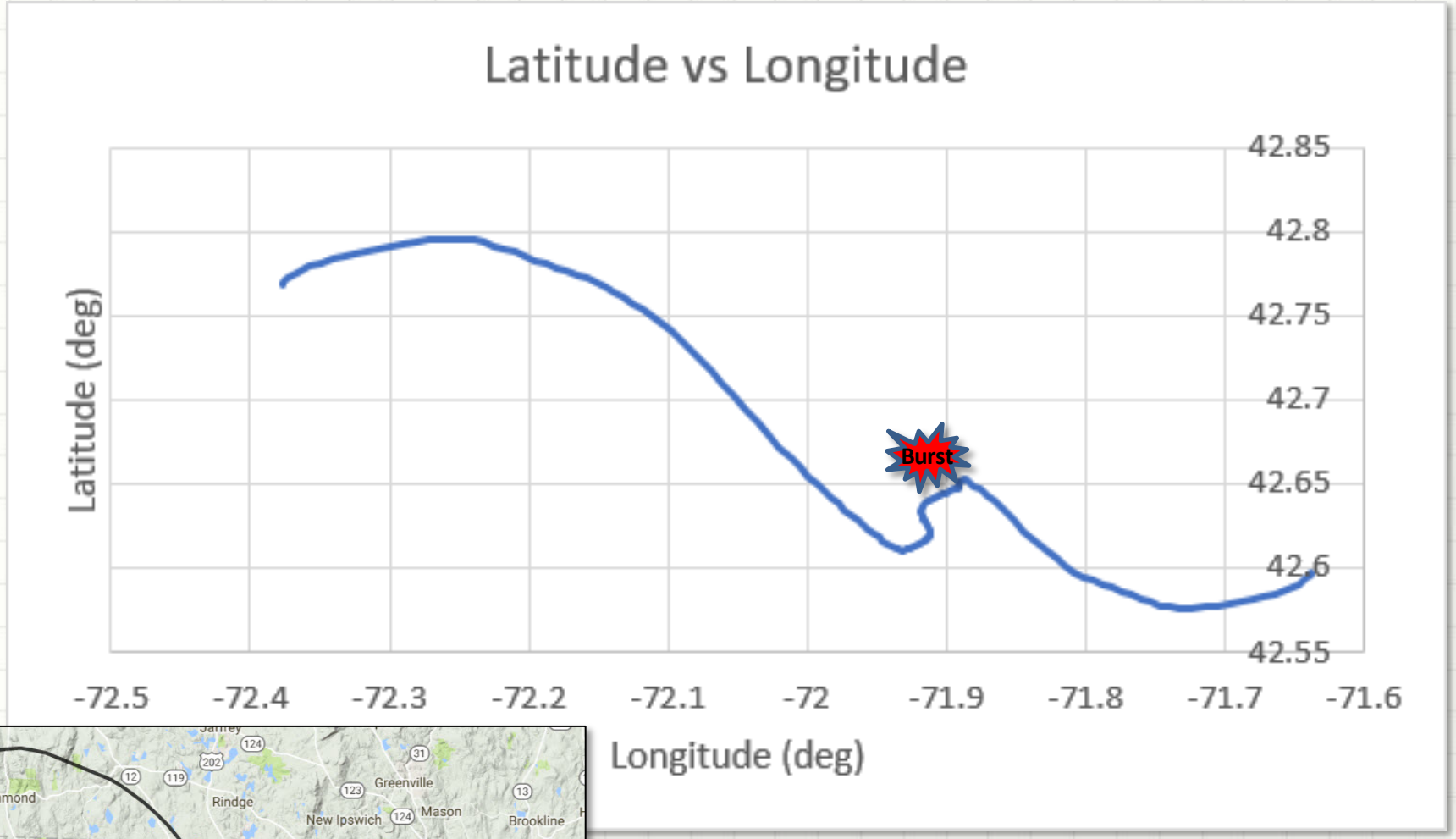
Raw Time (sec)	Lat (deg)	Lon (deg)	Alt (m)	Elapsed Time (min)	Alt (ft)
1491825600	42.7679	-72.377	0	0.0	0
1491825650	42.7693	-72.3764	263	0.8	861
1491825700	42.7721	-72.3731	525	1.7	1722
1491825750	42.776	-72.3659	788	2.5	2583
1491825800	42.7793	-72.3575	1050	3.3	3444
1491825850	42.7818	-72.3491	1313	4.2	4305
1491825900	42.7838	-72.3407	1575	5.0	5166

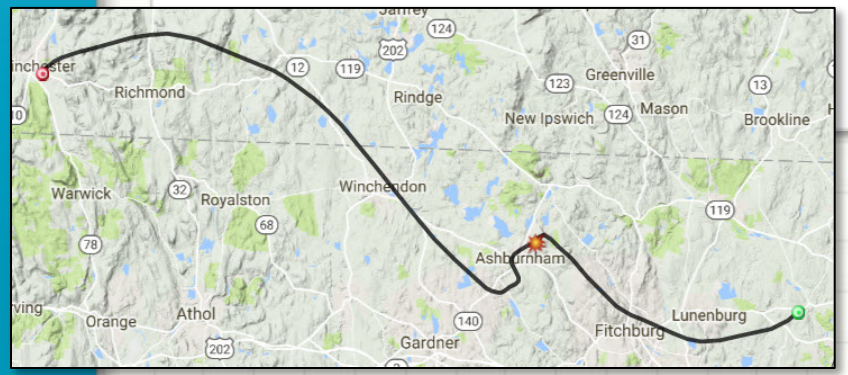
Sample Piece of Excel File

Results: Altitude vs Time



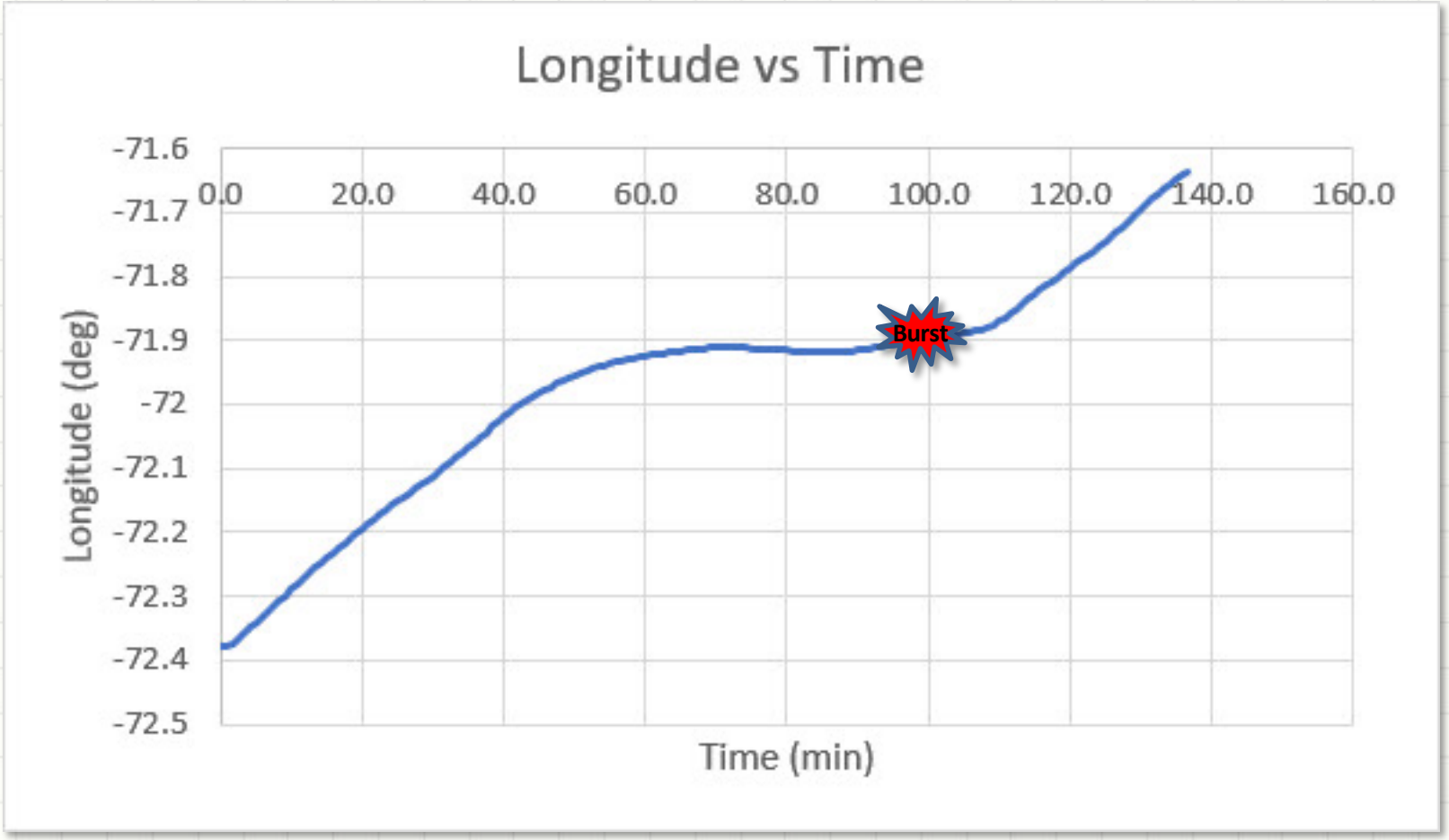
Results: Latitude vs Longitude





Data from website is used to plot path on map

Results: Longitude vs Time



- This plot provides some insight into the HAB ground speed vs time.
- What does this curve imply about a portion of the HAB's ground speed (and consequently what the Jetstream is doing)?

Hold These Days for Possible HAB-4 Launch

- Saturday/Sunday – April 6th/7th
  - Next Ham Bootcamp Saturday April 6th
- Saturday/Sunday – April 13th/14th
  - SOTA Activation Scheduled for Saturday April 13th
- Saturday/Sunday – April 20th/21st
- More if needed…

High Altitude Balloon Carrying Amateur Radio

HAB Tracking and Radios 1 – Following our HAB and its data

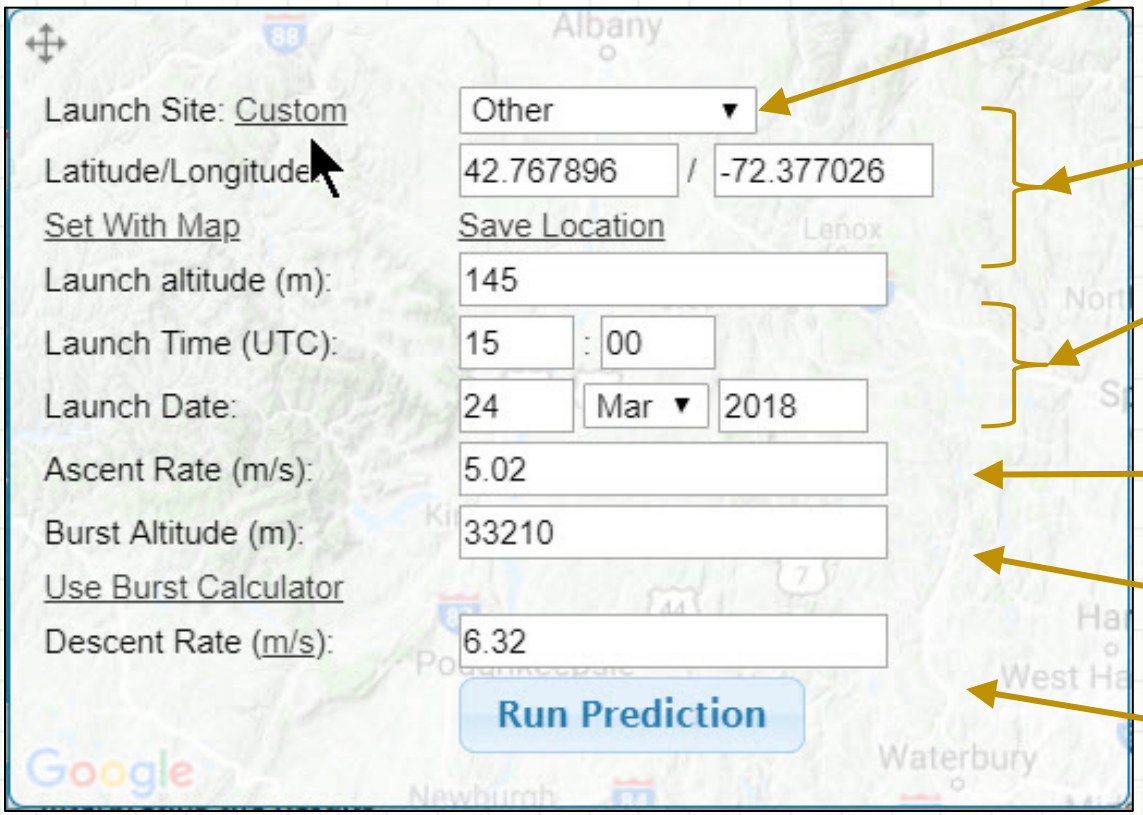
Nashua Area Radio Society

N1FD

Flight Prediction Inputs

We'll use an online software package from a HAB prediction site: http://predict.habhub.org/

Input Data Window



Save run, location, and results

Define launch location

Launch date and time

Average ascent speed

Burst altitude

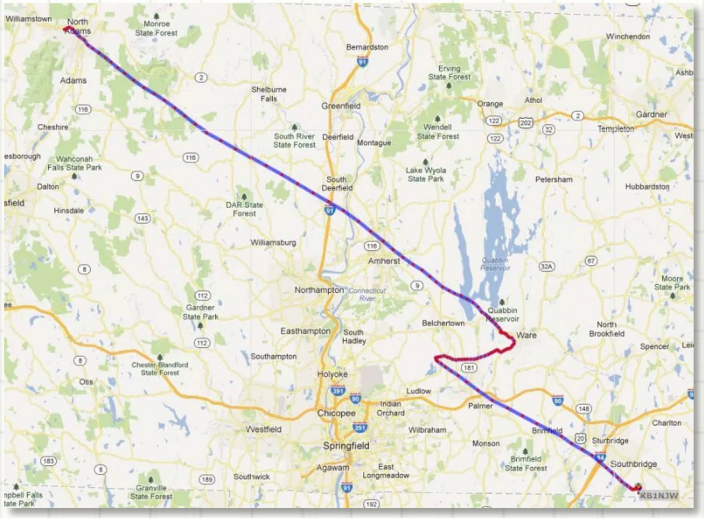
Descent rate (at impact)

HAB Flight Parameters

- Balloon Size: 1500 g
- Payload weight including parachute: 930 g
- Positive Lift: 1150 g
- Burst altitude: 33,420 m a.s.l.
  (~ 109,600 ft. or ~20.8 mi)
- Required Helium: 129 cu. ft.
- Average Ascent Rate: 5.07 m/s
- Ascent time: 110 mins
- Descent time: 41 mins
- Final descent speed: 5.92 m/s (~ 14 mph)
- Total flight time: 151 mins (2 hrs and 31 mins)

These parameters are conservative and should keep our HAB's total flight time at 2-1/2 hours and our landing speed safe.

Tracking the HAB



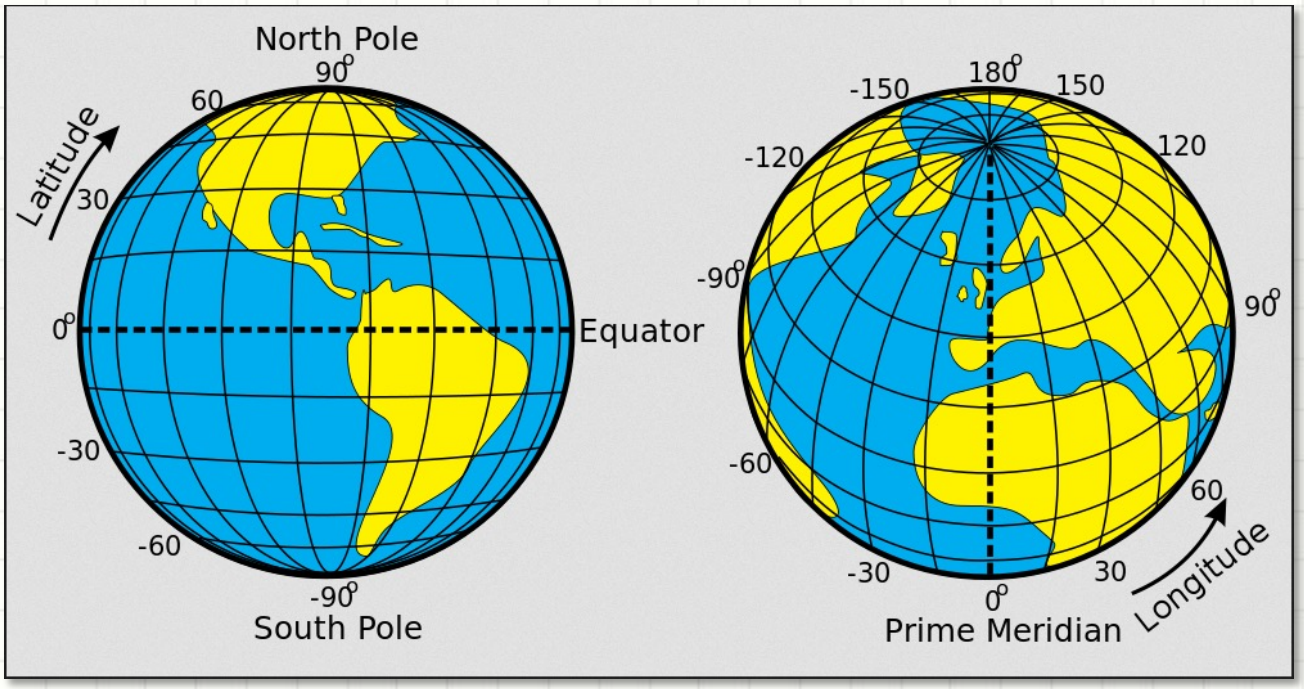
Predictions

- We can use physics to predict the HAB's flight altitude and path
- On board radios provide actual position to ground stations for tracking
- **GPS = Global Positioning System**: HAB location and altitude
- **APRS = Automatic Packet Reporting System**: Relays GPS data to ground stations
- Contact the FAA to alert them of our plans

GPS

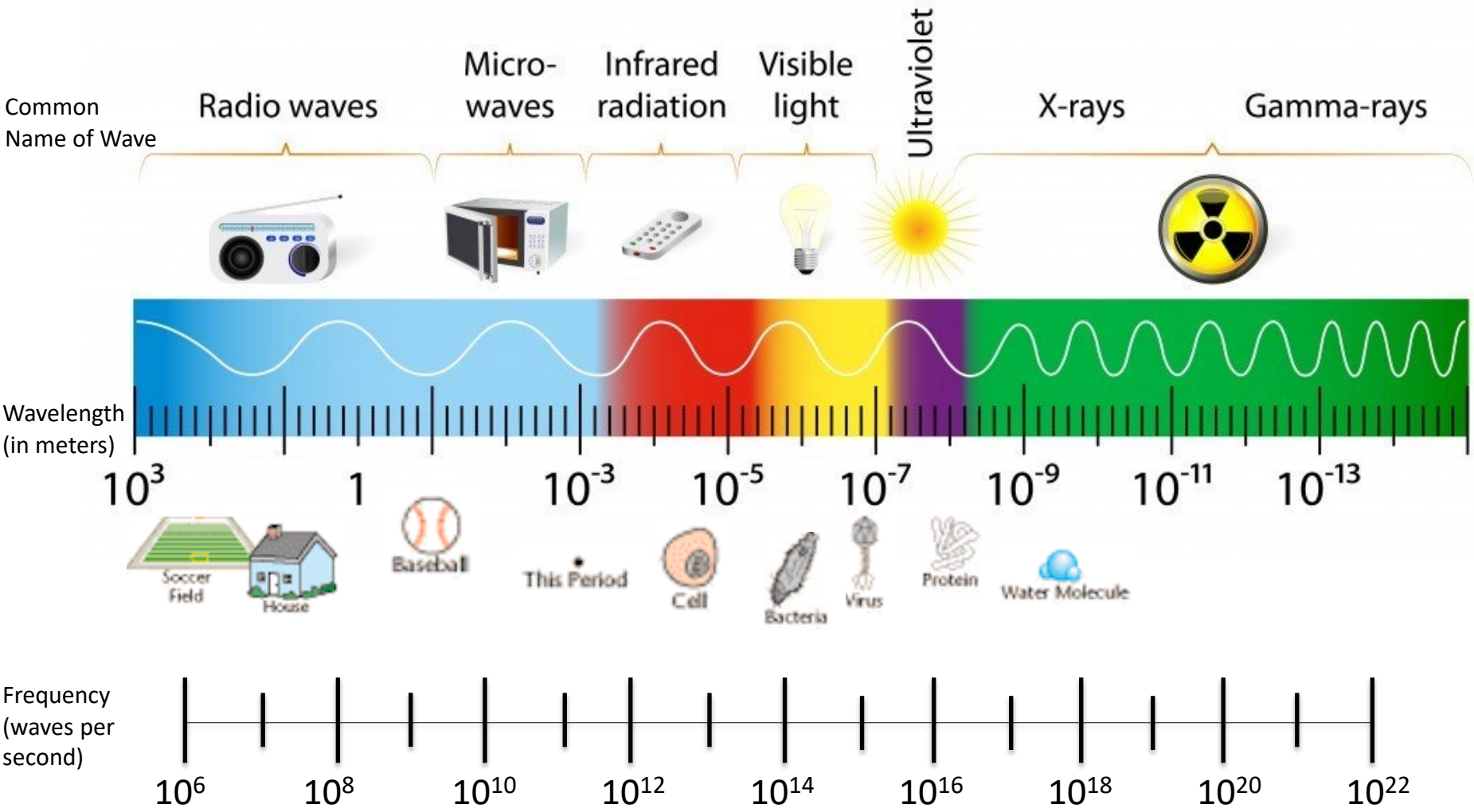
APRS

Relating Latitude and Longitude to Location

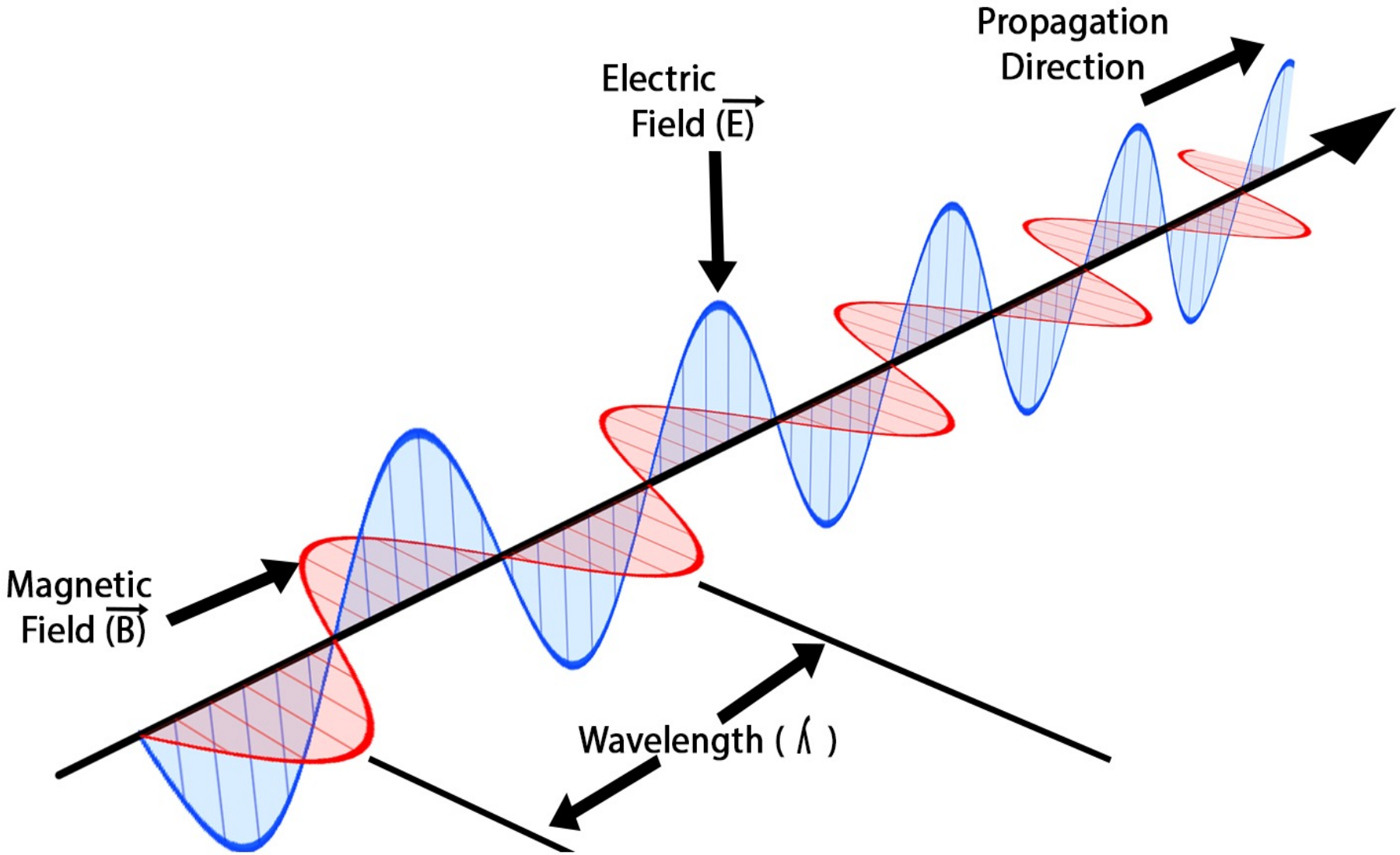


- Rules of Thumb:
  - Degrees of latitude are parallel so the distance between each degree remains almost constant.
  - But since degrees of longitude are farthest apart at the equator and converge at the poles, their distance varies greatly.
  - Each degree of latitude is **approximately 69 miles** (**111 kilometers**) apart
  - A degree of longitude is widest at the equator at **69.172 miles (111.321 km)** and gradually shrinks to zero at the poles.

THE ELECTROMAGNETIC SPECTRUM

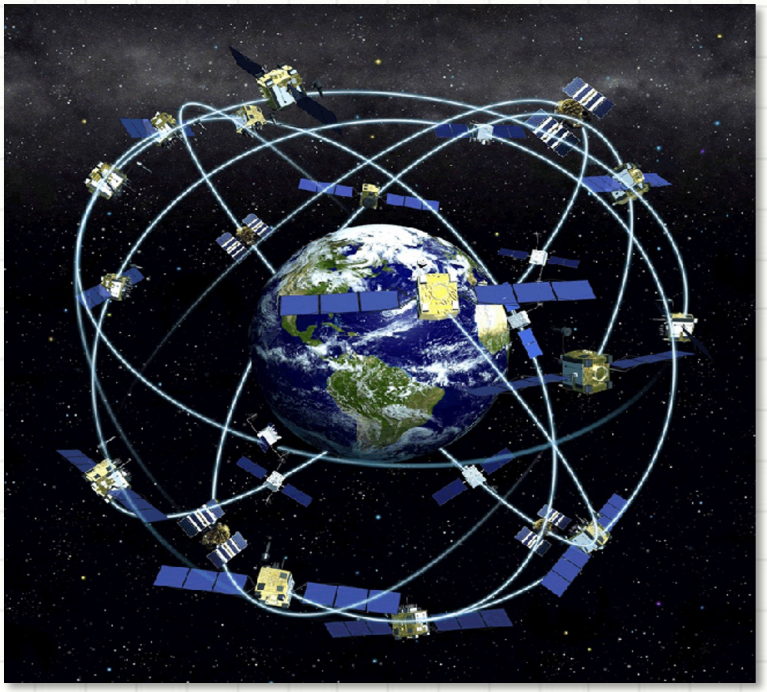


Electromagnetic Wave



GPS Satellites

- GPS is a network of 31 Satellites orbiting at ~20,000 km
- Developed for US military navigation, now used by everyone



- Anywhere on the planet there are at least four GPS satellites visible
  - 3 Satellites required to fix your position on the earth
  - 4 Satellites required for clock deviation correction (1 additional)
- GPS device uses a process called **Trilateration** to fix your position

GPS Tracking

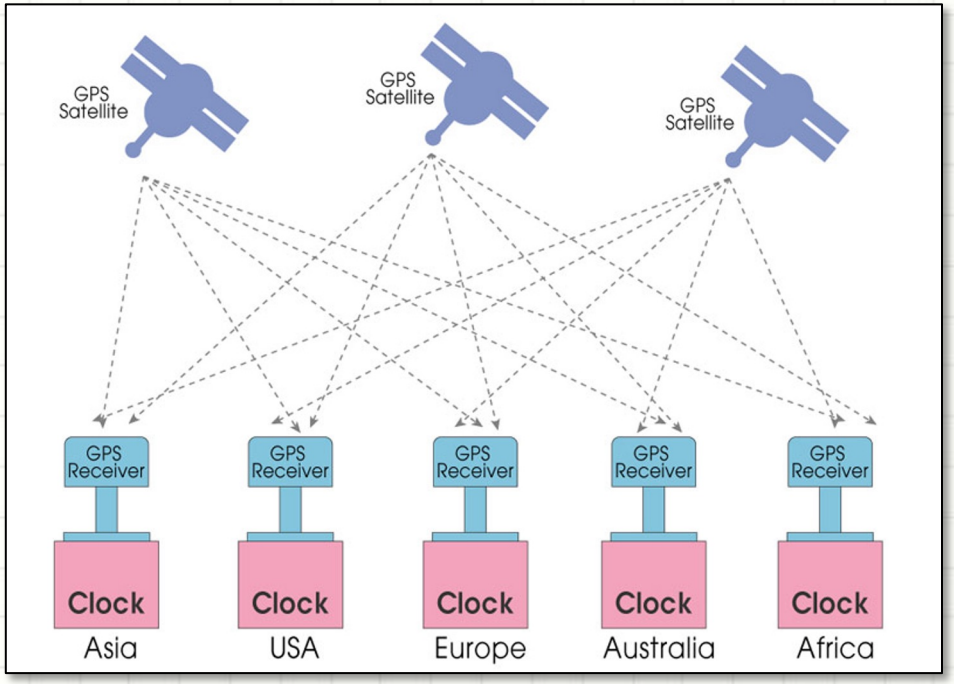
Process of Trilateration

[Video on YouTube]

- If you know how far away you are from satellite A, then you know you must be located somewhere in the Red circle
- If you know the same for Satellites B and C you can fix your position

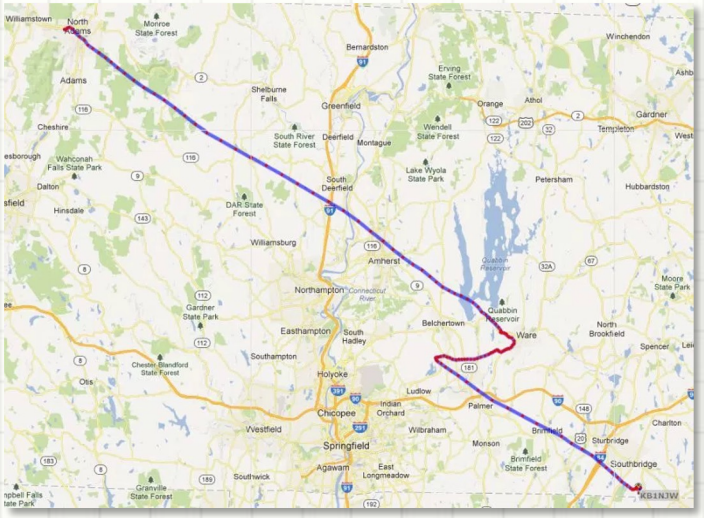
How GPS Works

It's all about time



- Each GPS satellite transmits its location and the exact time.
- All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant.
- The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are further away than others.
- The distance to the GPS satellites can be determined by the amount of time it takes for their signals to reach the receiver.
- When the receiver estimates the distance to at least four GPS satellites, it can calculate its position in three dimensions.

Tracking the HAB



Predictions

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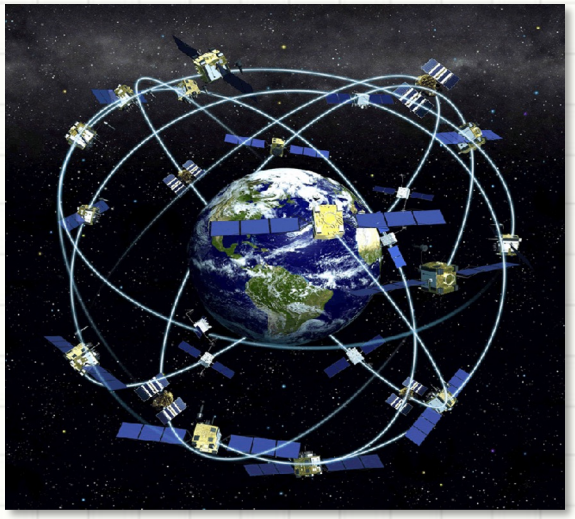


GPS

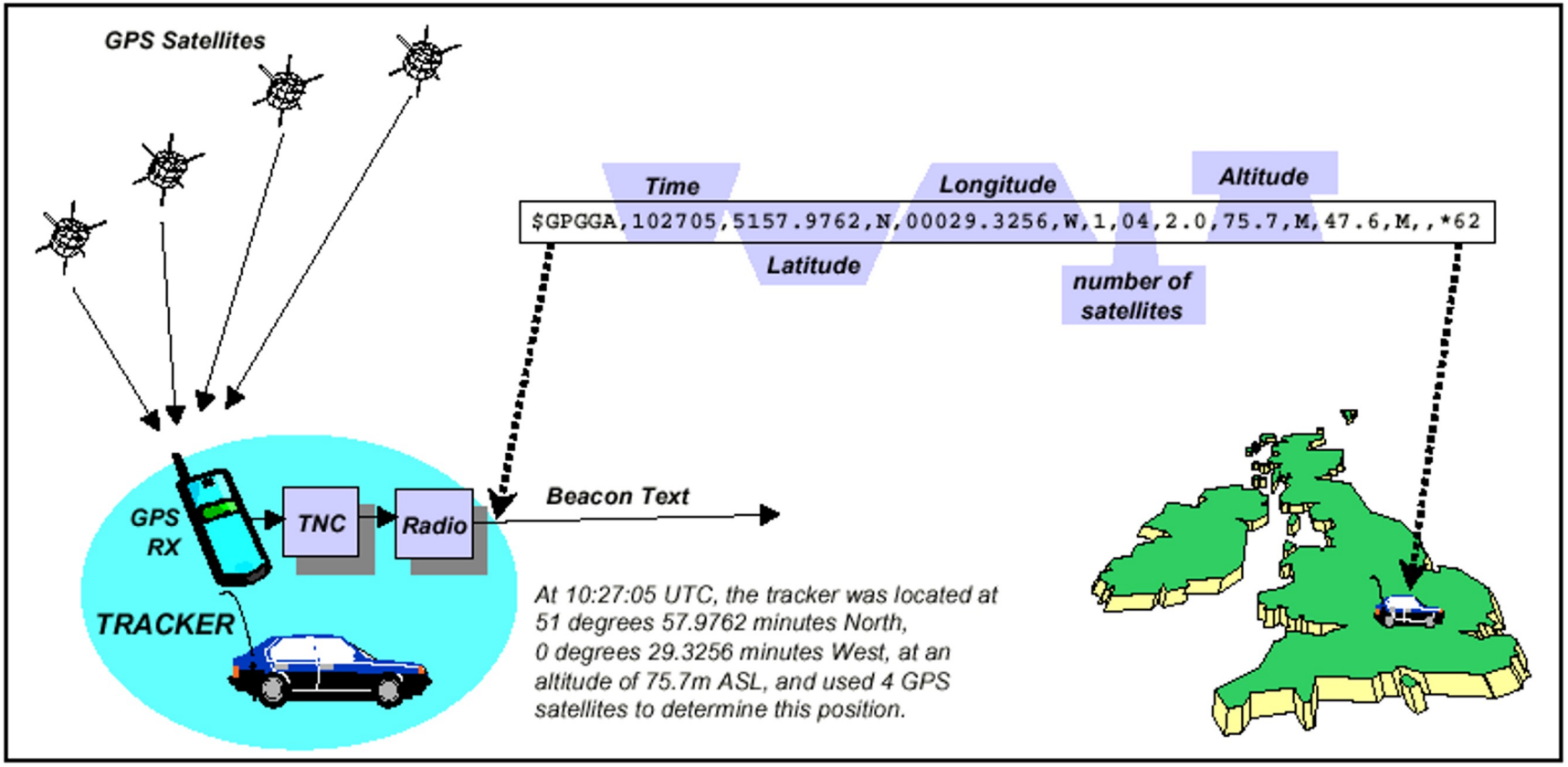
APRS

APRS: Automatic Packet Reporting System

Video on YouTube

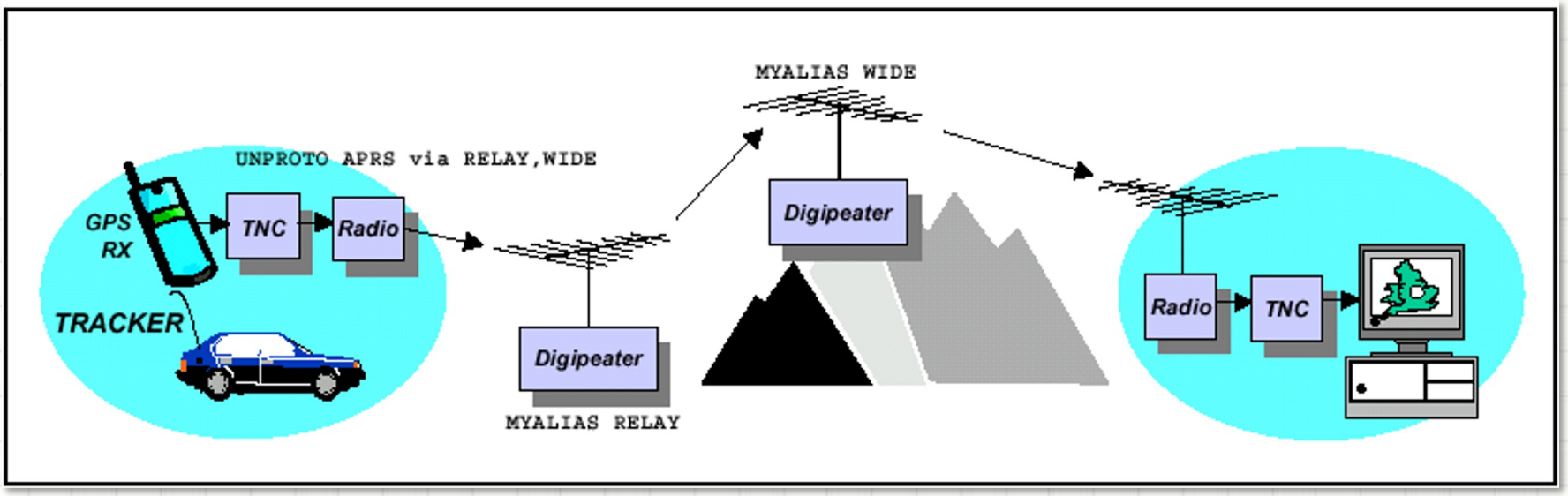
APRS: Automatic Packet Reporting System

Position Information is Determined From GPS



Transmiting APRS Information

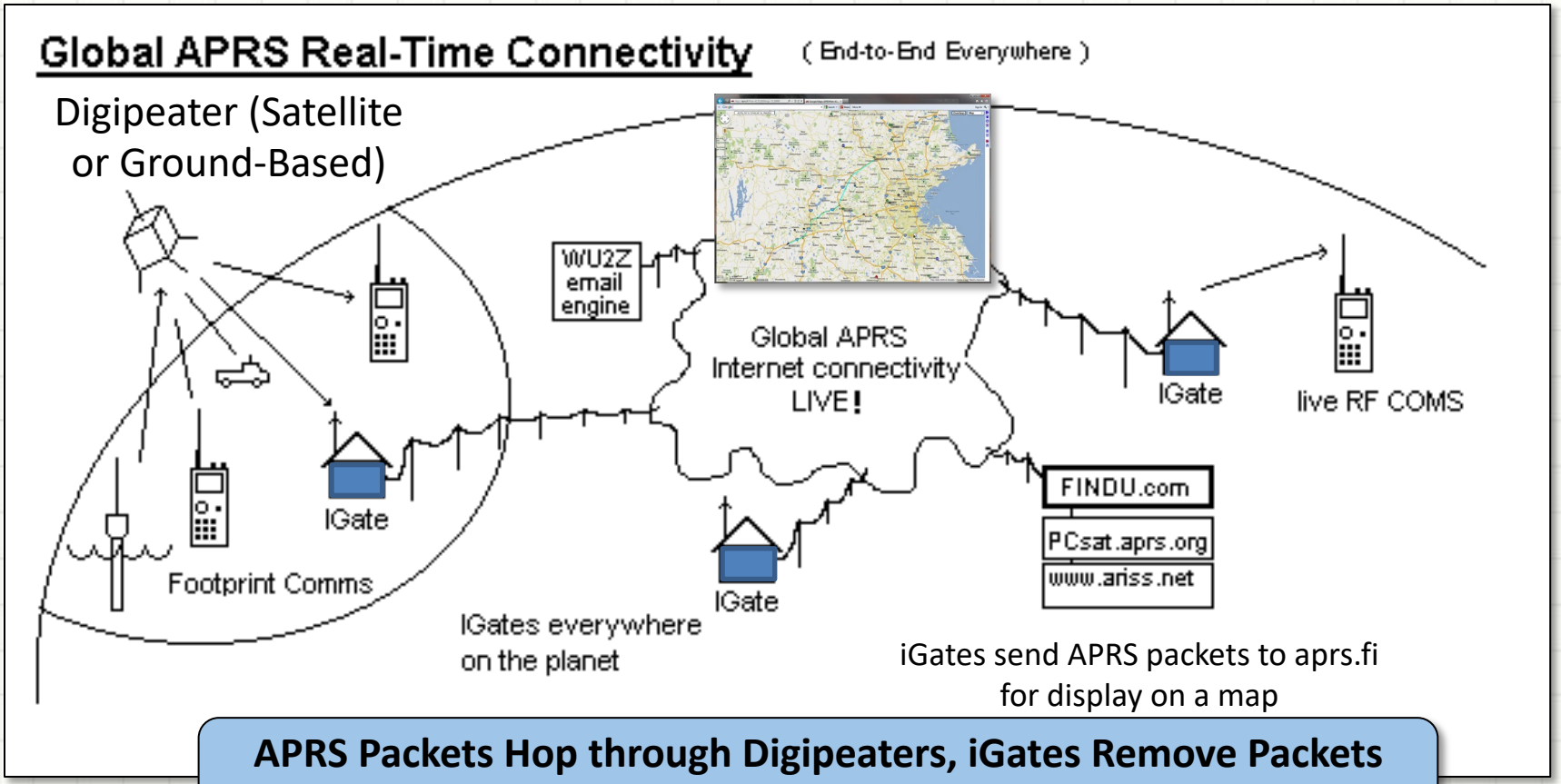
Using Radio Frequency = 144.390 MHz



Amateur Radio Ground-based *Digipeaters* listen for APRS packets on 144.390 and forward them

APRS Network

Forwarding Position Data From Around the World



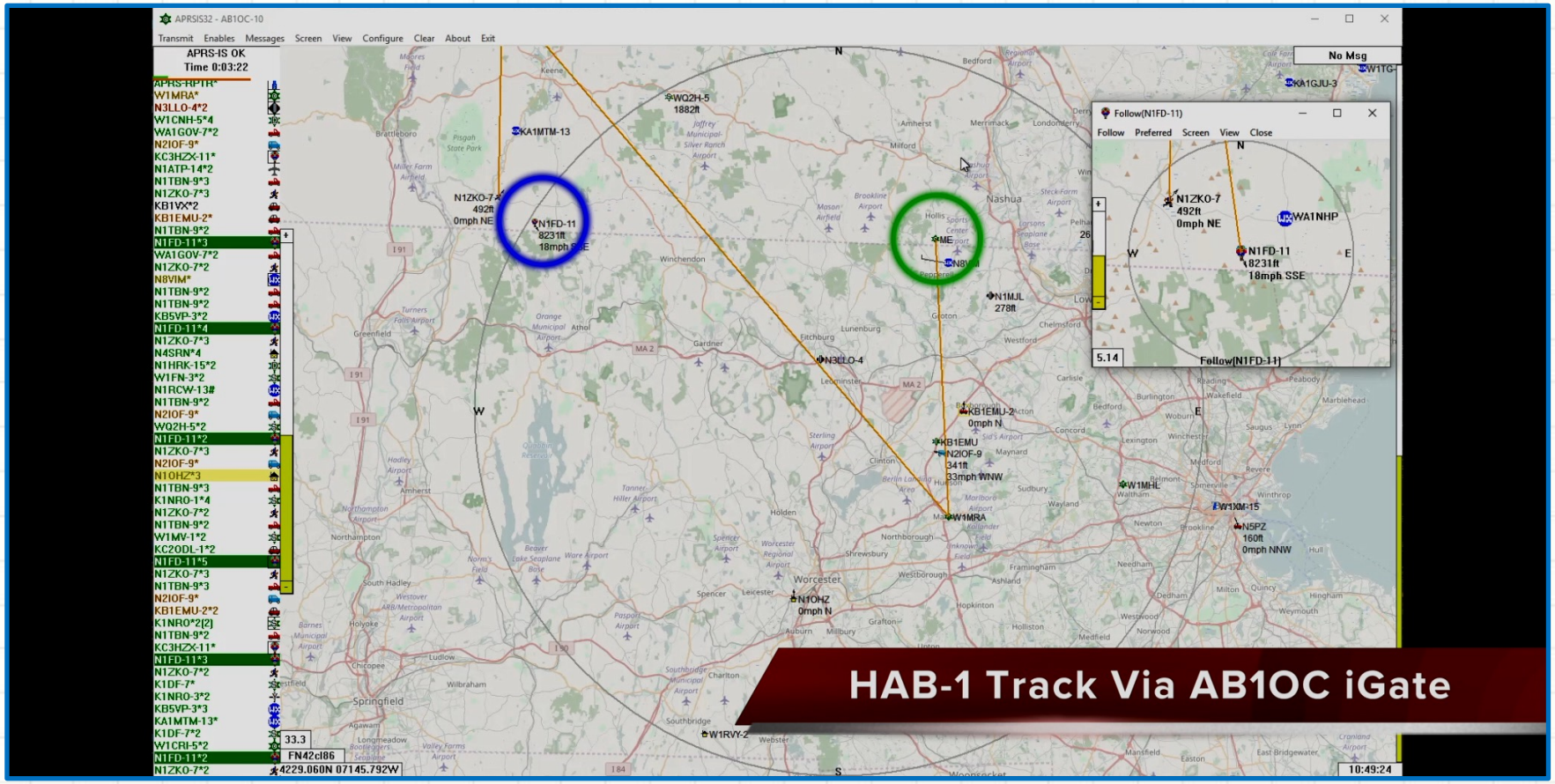
APRS Packets Hop through Digipeaters, iGates Remove Packets from the APRS Network and Forward Them to APRS.fi

Altitude	Path	Path Description
Under 3000 m	WIDE1-1, WIDE2-2	Packet repeated up to three times.
Between 3000 and 5000 m	WIDE2-2	Packet repeated up to two times.
Above 5000 m	WIDE2-1	Packet repeated up to one time.

APRS Network Operation

[HAB-1 APRS Video]

Digipeaters and iGates Relay Information to The Internet

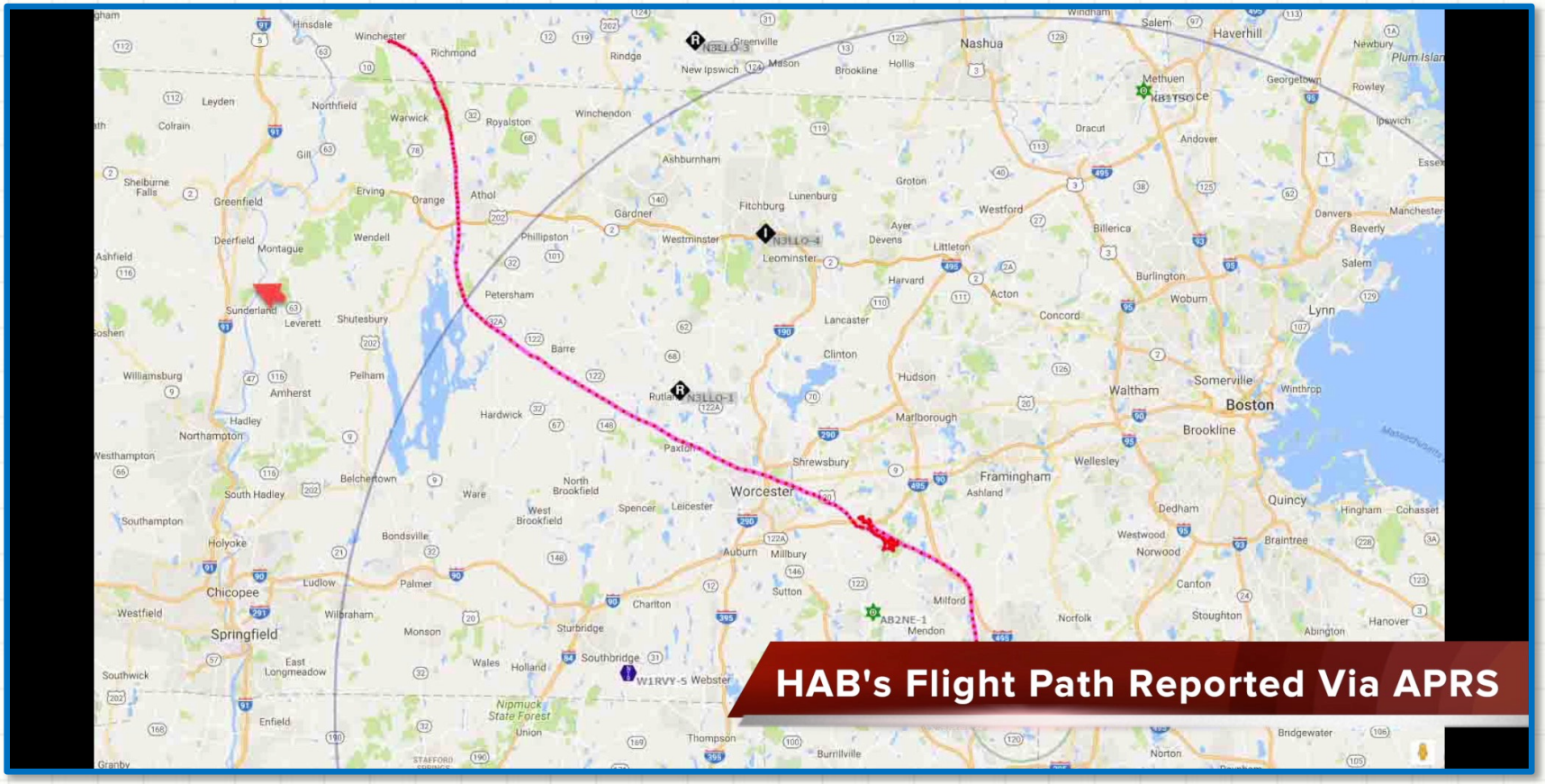


APRS Tracking HAB-1's Flight to Near Space and Back

APRS Network Operation

HAB-1 Flight Track Video

Digipeaters and iGates Relay Information to The Internet



Actual APRS Network Operation Tracking HAB-1

High Altitude Balloon Carrying Amateur Radio

HAB Tracking and Radios 2 – Hands on with tracking tools

Nashua Area Radio Society

N1FD

APRS Packets

HAB Packets on aprs.fi

HAB Packets (From our HAB Test Session via aprs.fi)

- **Call Sign** – identifies the person or group licensed to transmit
  - May include information about the type of station they are using

N1FD -11

The Nashua Area Radio Society

Type for Balloon, Aircraft or Spacecraft

```
2017-04-07 21:16:50 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO148/000/A=000351RadBug,16C,984mb,3,001
2017-04-07 21:17:50 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,AB1OC-10:!4242.70N/07135.41WO148/000/A=000354RadBug,10C,984mb,3,002
2017-04-07 21:18:50 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO148/000/A=000360RadBug,08C,985mb,3,003
2017-04-07 21:19:50 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,AB1OC-10:!4242.70N/07135.41WO148/000/A=000360RadBug,06C,985mb,3,004
2017-04-07 21:20:50 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO148/000/A=000347RadBug,05C,985mb,3,005
2017-04-07 21:21:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO148/000/A=000344RadBug,05C,985mb,3,006
2017-04-07 21:22:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO174/000/A=000347RadBug,04C,985mb,3,007
2017-04-07 21:23:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO174/000/A=000344RadBug,04C,985mb,3,008
2017-04-07 21:24:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO325/000/A=000347RadBug,04C,985mb,3,009
2017-04-07 21:25:52 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO325/000/A=000351RadBug,04C,985mb,3,010
2017-04-07 21:26:52 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,AB1OC-10:!4242.70N/07135.41WO325/000/A=000351RadBug,04C,985mb,3,011
2017-04-07 21:27:52 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO325/000/A=000351RadBug,04C,985mb,3,012
2017-04-07 21:28:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO325/000/A=000351RadBug,04C,985mb,3,013
2017-04-07 21:29:52 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,AB1OC-10:!4242.70N/07135.41WO109/000/A=000351RadBug,04C,985mb,3,014
2017-04-07 21:30:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO109/000/A=000347RadBug,04C,985mb,3,015
2017-04-07 21:31:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO109/000/A=000351RadBug,04C,985mb,3,016
2017-04-07 21:32:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO266/000/A=000360RadBug,04C,985mb,3,017
2017-04-07 21:33:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO266/000/A=000360RadBug,04C,985mb,3,018
2017-04-07 21:34:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO266/000/A=000360RadBug,04C,985mb,3,019
2017-04-07 21:35:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO269/000/A=000364RadBug,04C,985mb,3,020
2017-04-07 21:36:51 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.71N/07135.41WO269/000/A=000367RadBug,08C,985mb,3,021
2017-04-07 21:37:52 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,AB1OC-10:!4242.71N/07135.41WO045/001/A=000364RadBug,13C,984mb,3,022
2017-04-07 21:38:52 EDT: N1FD-11>CQ,WIDE1-1,WIDE2-2,qAR,AB1OC-10:!4242.71N/07135.41WO056/000/A=000367RadBug,15C,984mb,3,023
```

Actual Packets from our HAB during a test

APRS Packets

HAB Packets on aprs.fi

Station Service Set Identifiers (SSIDs)

iPhone APRS Station (ex. AB1OC-5)

Handheld Transceiver or HT (ex. AB1OC-7)

iGates (ex. AB1OC-10)

Our HAB is a Balloon (ex. N1FD-11)

SSID	Description
-0	Your primary station usually fixed and message capable
-1	Generic additional station, digi, mobile, wx, etc
-2	Generic additional station, digi, mobile, wx, etc
-3	Generic additional station, digi, mobile, wx, etc
-4	Generic additional station, digi, mobile, wx, etc
-5	Other networks (Dstar, Iphones, Androids, Blackberry's etc)
-6	Special activity, Satellite ops, camping or 6 meters, etc
-7	Walkie talkies, HT's or other human portable
-8	Boats, sailboats, RV's or second main mobile
-9	Primary Mobile (usually message capable)
-10	Internet, Igates, echolink, winlink, AVRS, APRN, etc
-11	Balloons, aircraft, spacecraft, etc
-12	APRStt, DTMF, RFID, devices, one-way trackers*, etc
-13	Weather stations
-14	Truckers or generally full time drivers
-15	Generic additional station, digi, mobile, wx, etc

APRS SSID Tells Us What Type Of Device We ARE Tracking.

APRS Packet Sequence

Understanding and Analyzing the Data

HAB Packets on aprs.fi

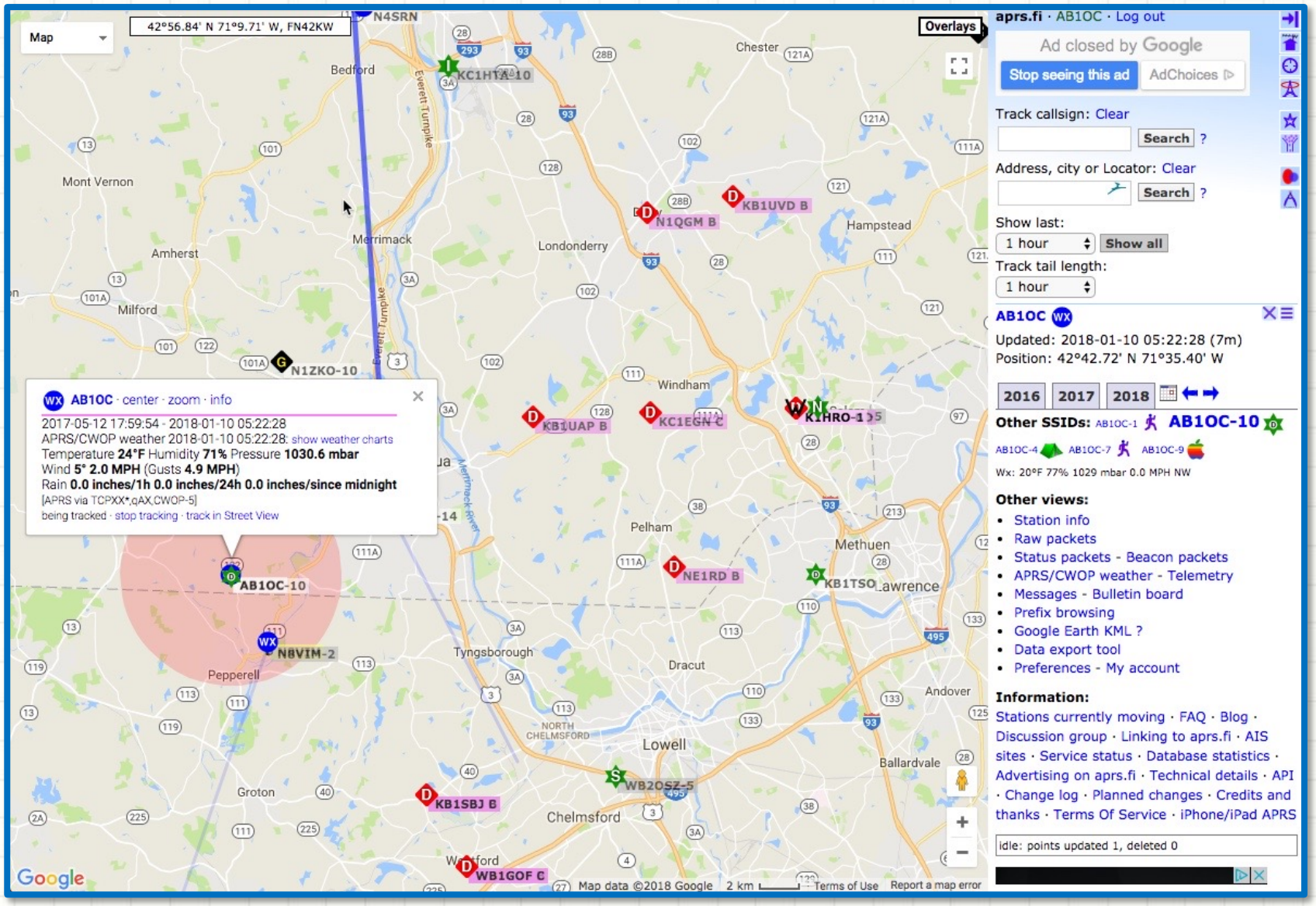
2017-04-07 21:16:50 EDT: **N1FD-11**>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO148/000/A=000351RadBug,16C,984mb,3,001

Date/Time	HAB Callsign	APRS Msg. Header	Packet Source (iGate)	iGate Callsign	Latitude (deg - min)	Longitude (deg - min)	Heading (deg. N)	Speed (m/s)	Altitude (feet)	Temperature (deg. C)	Pressure (mBar)	Packet #
2017-04-07 21:16:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	351	16	984	1
2017-04-07 21:17:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.70N	71 35.41W	148	0	354	10	984	2
2017-04-07 21:18:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	360	8	985	3
2017-04-07 21:19:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.70N	71 35.41W	148	0	360	6	985	4
2017-04-07 21:20:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	347	5	985	5
2017-04-07 21:21:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	344	5	985	6
2017-04-07 21:22:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	174	0	347	4	985	7
2017-04-07 21:23:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	174	0	344	4	985	8
2017-04-07 21:24:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	347	4	985	9
2017-04-07 21:24:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	10
2017-04-07 21:26:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	11
2017-04-07 21:27:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	12
2017-04-07 21:28:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	13
2017-04-07 21:29:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.70N	71 35.41W	109	0	351	4	985	14
2017-04-07 21:30:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	109	0	347	4	985	15
2017-04-07 21:31:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	109	0	351	4	985	16
2017-04-07 21:32:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	266	0	360	4	985	17
2017-04-07 21:33:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	266	0	360	4	985	18
2017-04-07 21:34:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	266	0	360	4	985	19
2017-04-07 21:35:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	269	0	364	4	985	20
2017-04-07 21:36:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.71N	71 35.41W	269	0	367	8	985	21
2017-04-07 21:37:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.71N	71 35.41W	45	1	364	13	984	22
2017-04-07 21:38:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.71N	71 35.41W	45	0	367	15	984	23

Using APRS.fi to Track our HAB

Hand-on Activity

[HAB Packets on aprs.fi]



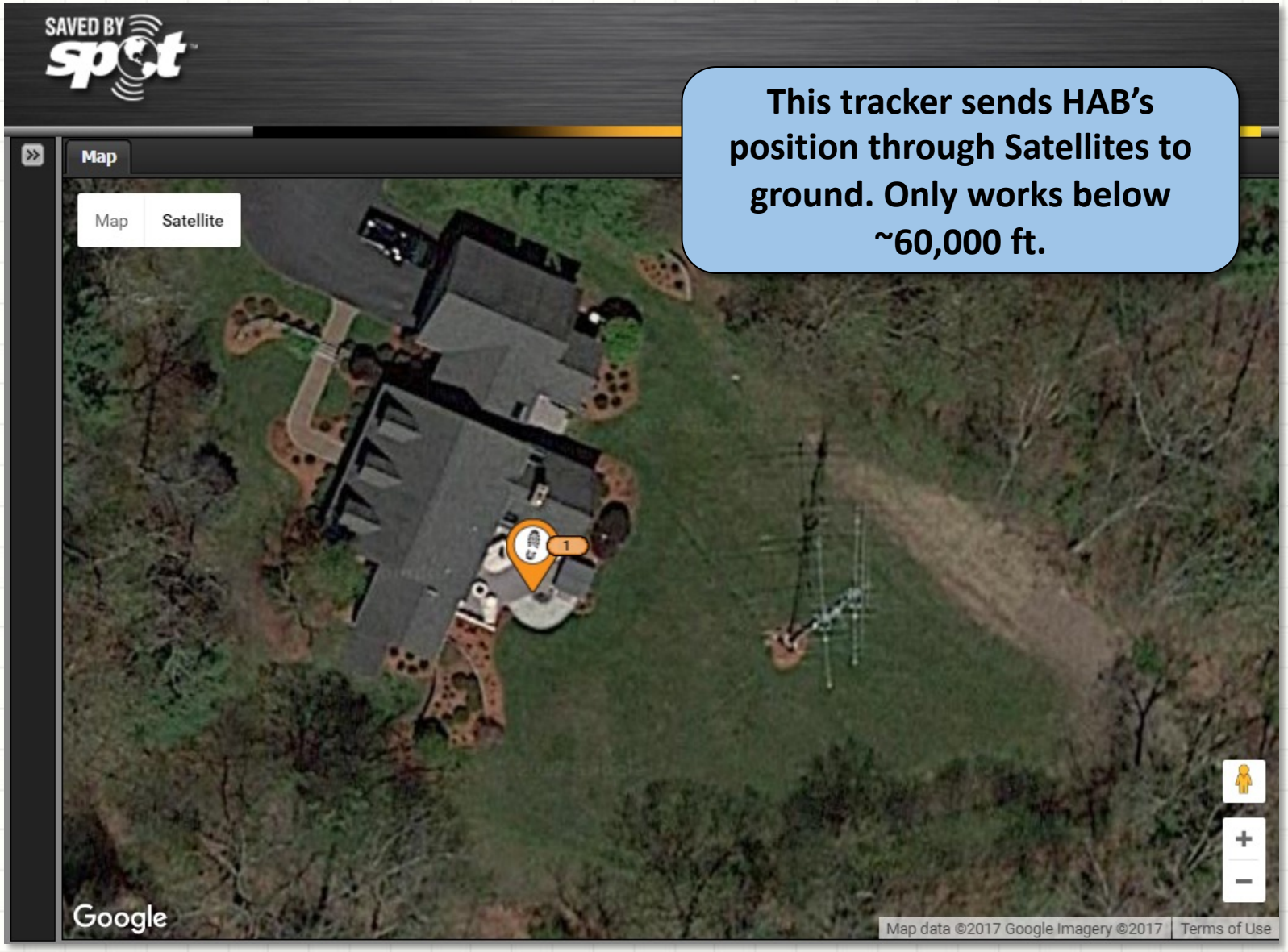
Using a Radio to Track our HAB

Hand-on Activity

[HAB Packets on aprs.fi]

Satellite Tracker

Backup to APRS - [See HAB's Current Location]



This tracker sends HAB's position through Satellites to ground. Only works below ~60,000 ft.

High Altitude Balloon Carrying Amateur Radio

Space Communications – What's up and how can we communicate using it?

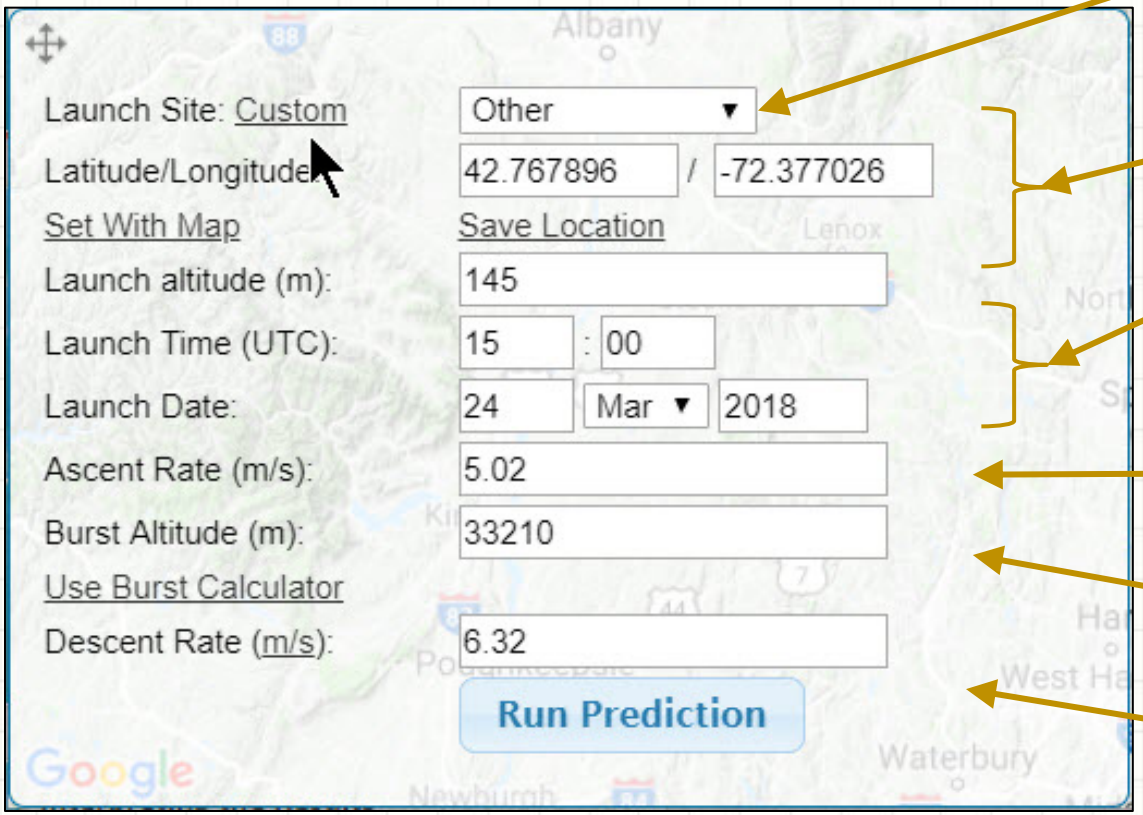
Nashua Area Radio Society

N1FD

Flight Prediction Inputs

We'll use an online software package from a HAB prediction site: http://predict.habhub.org/

Input Data Window



Save run, location, and results

Define launch location

Launch date and time

Average ascent speed

Burst altitude

Descent rate (at impact)

HAB Design Parameters

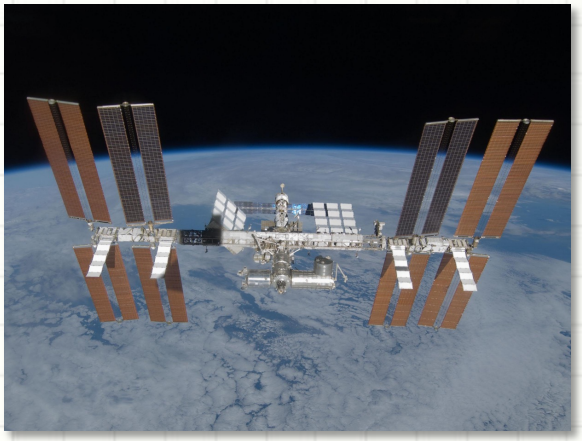
- Balloon Size: 1500 g
- Payload weight including parachute: 1040 g
- Positive Lift: 1150 g
- Burst altitude: 33,210 m a.s.l.
  (~ 108,900 ft. or ~20 mi)
- Required Helium: 133 cu. ft.
- Average Ascent Rate: 5.02 m/s
- Ascent time: 111 mins
- Descent time: 42 mins
- Final descent speed: 6.32 m/s (~ 14 mph)
- Total flight time: 153 mins (2 hrs and 35 mins)

These parameters are conservative and should keep our HAB's total flight time under 2-3/4 hours and our landing speed safe.

Space Communications

What will we be learning about?

- What's in space that is used for communications?
- How do communications satellites work?
- How do orbits work?
- What about Doppler Shift?
- Space Communications Demonstrations
  - Satellite Ground Station
  - Communicating through a satellite
  - Receiving an image from the ISS
  - ISS Astronaut Contact using Amateur Radio



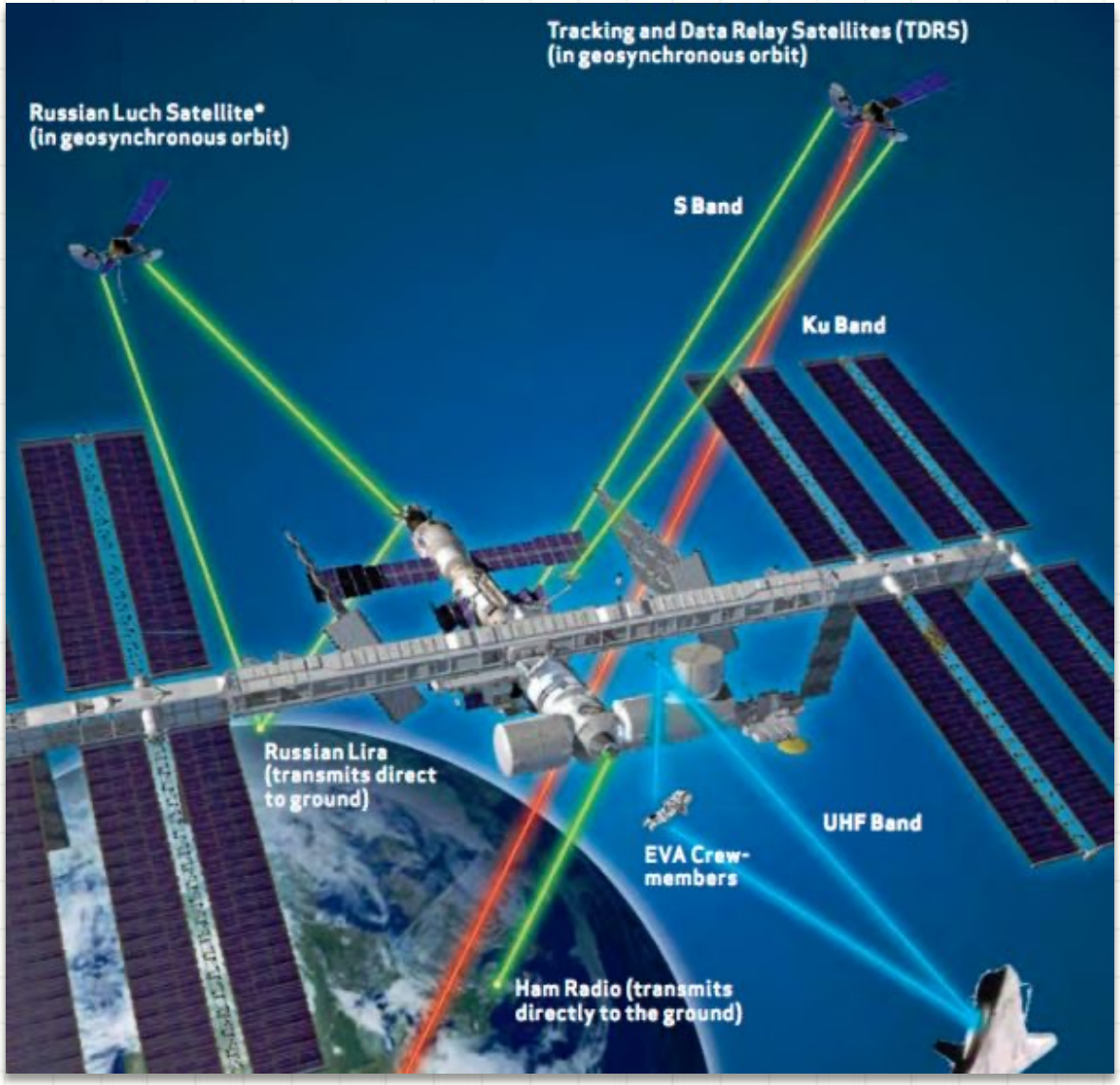
ISS Communications

Multiple channels support different purposes

Transmission of voice, data, and video for multiple users

ISS Communications

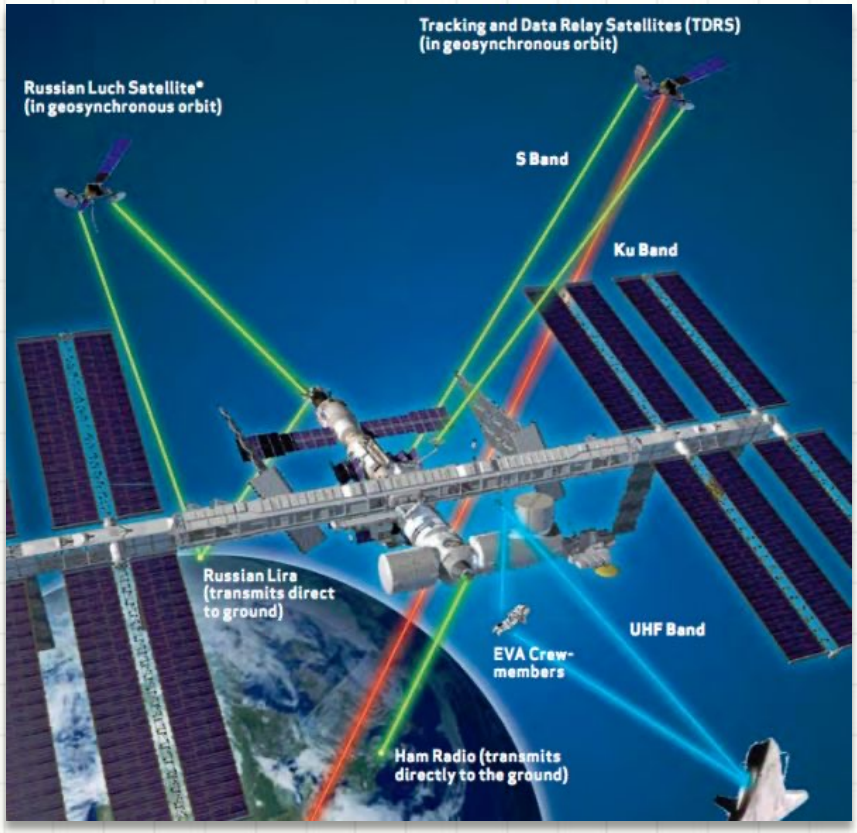
Multiple channels for different purposes



Multiple Radio Channels (frequencies) Aboard The ISS Serve Different Purposes

ISS Communications

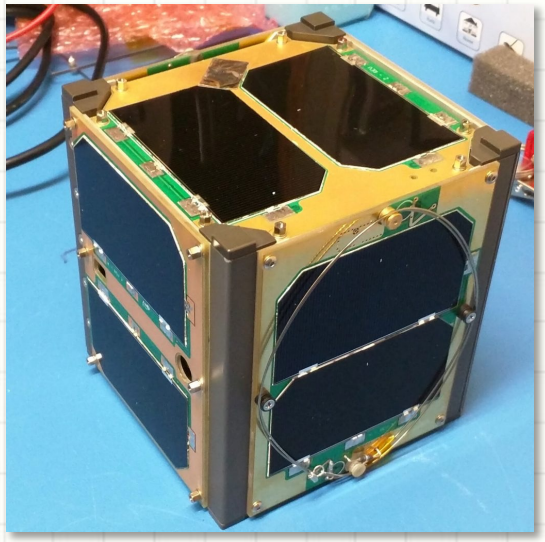
Multiple channels for different purposes



Multiple Radio Channels
Aboard The ISS Serve Different Purposes

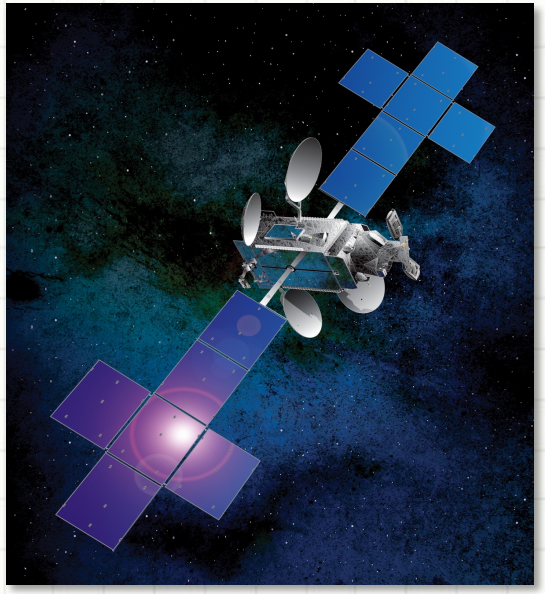
- S and Ku band links use Tracking and Data Relay Satellites (TDRS) to communicate with NASA ground control
  - S-Band links (2-4 GHz) for audio communications
  - Ku-Band links (12 - 18 GHz) for audio, video and high-speed data
  - Ku-band system also provides 10 Mbit/s network access to laptops on ISS
- UHF links (300 MHz – 1 GHz) for space walks and near-space audio comms.
- VHF (~145 MHz) links for Amateur Radio ground communications

A Modern Satellite Examples

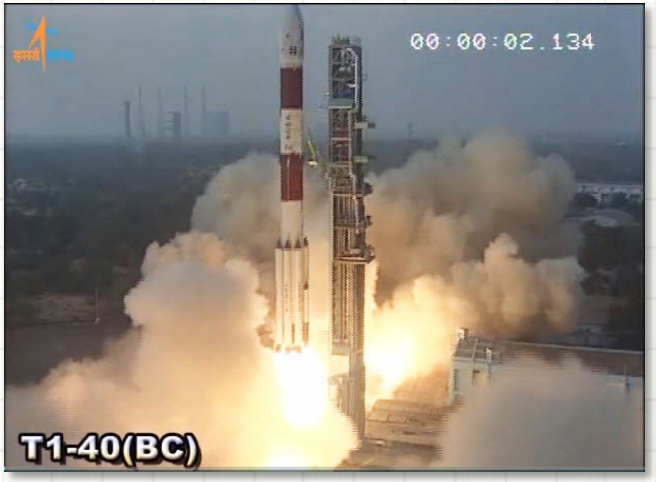


Amateur Communications AO-92 (LEO)

GPS Phase III Satellite (MEO)

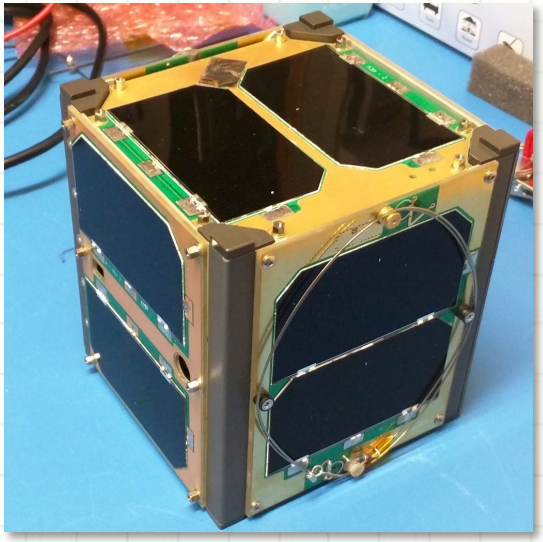


DirecTV 14 Satellite (GEO)

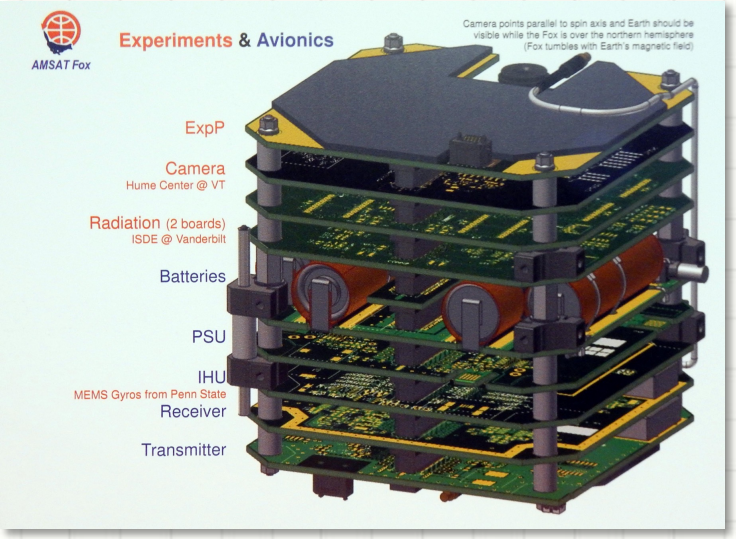


Satellite Launch and Deployment
(PSLV-C40 Mission Deploys Satellites Including AO-92)

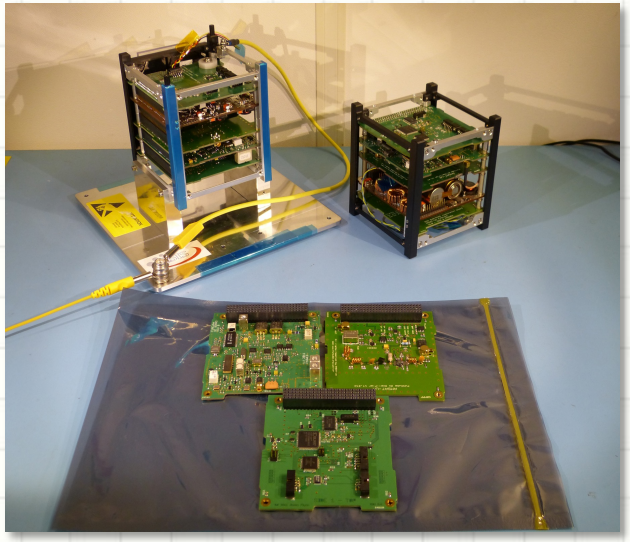
Amateur CubeSat – What's inside?



Amateur Communications AO-92 (LEO)



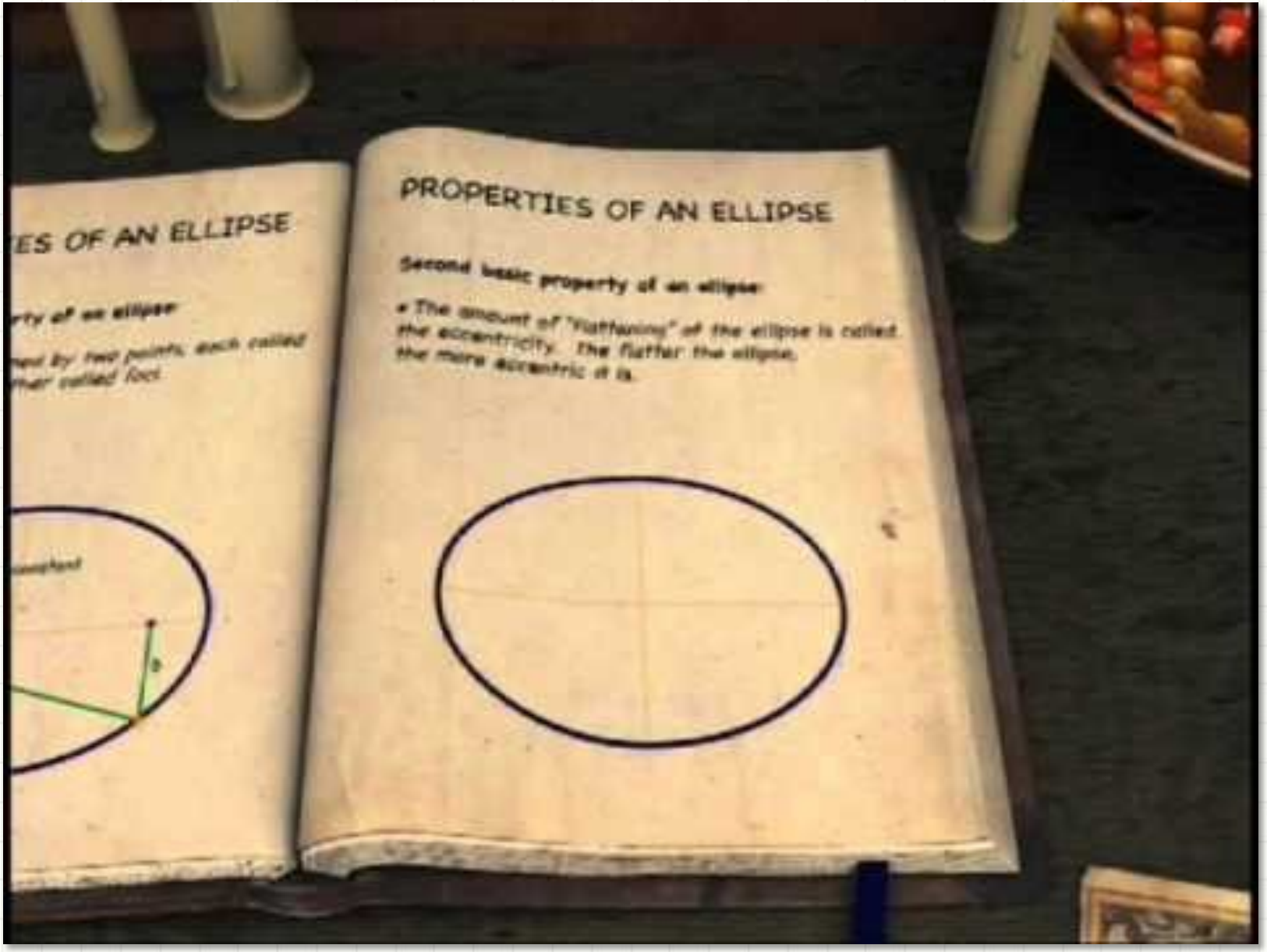
AO-92 Internal Electronics



AO-92 (Fox-1) Boards

How Large is a CubeSat?

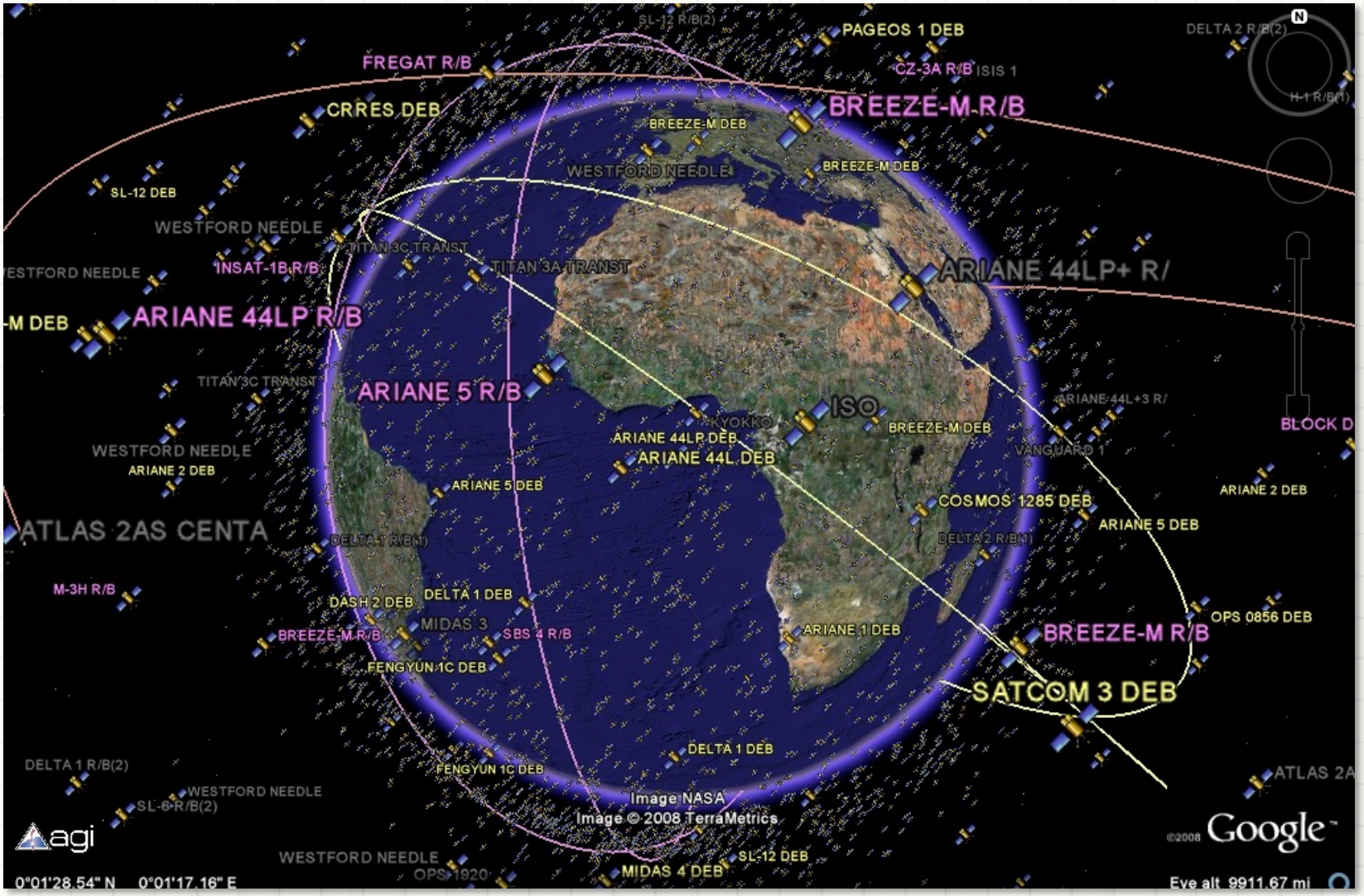
Kepler's Three Laws Of Orbital Motion



Video on YouTube

Lots of Objects in Earth Orbit

How do we know where things are?



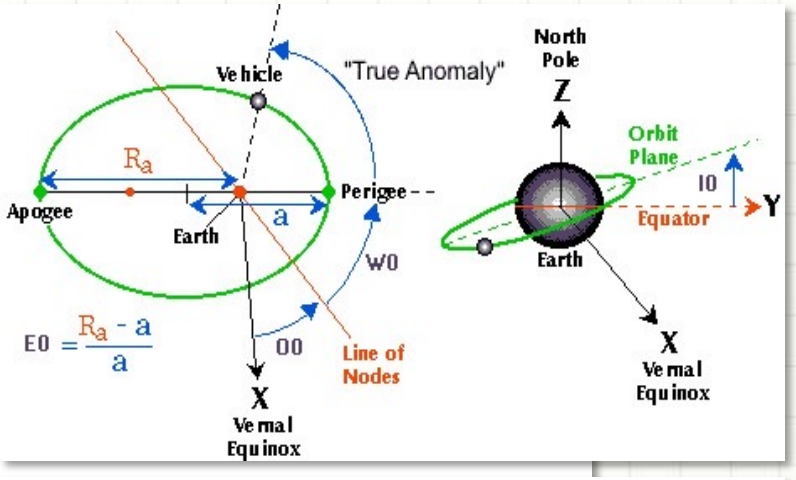
We can use Kepler's Laws to Understand and Characterize Earth Orbits

How Do Communication Satellites Work?

Video on YouTube

Satellite Orbit Predictions

Kepler's Laws & Software




```
SO-50
1 27607U 02058C   18018.48571608 -.00000036  00000-0  15427-4 0  9997
2 27607  64.5539 187.5994 0047014   5.7119 354.4509 14.75412723810878
```

```
MacDoppler Predictions: SO-50
Kep Set:          999
Times:            Local Time
Location:         Hollis NH USA
Latitude:         42.7118 Degrees
Longitude:        -71.5902 Degrees
Elevation:        105.0 Meters
Run on:           2017/05/09 08:09:43 America/New_York
```

	Date	Time	Azimuth	Elevation	Downlink	Uplink
Rise:	2017/05/09	08:24:22	337.2	0.0	436.79960	145.84847
Max:	2017/05/09	08:27:57	9.5	3.4	436.79501	145.85000
Set:	2017/05/09	08:31:30	41.5	0.0	436.79046	145.85152
Rise:	2017/05/09	10:05:01	337.7	0.0	436.80261	145.84746
Max:	2017/05/09	10:10:41	34.3	13.0	436.79500	145.85000
Set:	2017/05/09	10:16:18	90.6	0.0	436.78738	145.85254
Rise:	2017/05/09	11:45:09	327.3	0.1	436.80468	145.84677
Max:	2017/05/09	11:51:59	55.4	69.7	436.79496	145.85001
Set:	2017/05/09	11:58:46	141.3	0.0	436.78531	145.85324
Rise:	2017/05/09	13:26:19	306.5	0.0	436.80296	145.84734
Max:	2017/05/09	13:31:52	251.2	13.6	436.79501	145.85000
Set:	2017/05/09	13:37:24	195.8	0.0	436.78711	145.85263

Kepler's Laws plus a set of numbers let software predict orbital paths

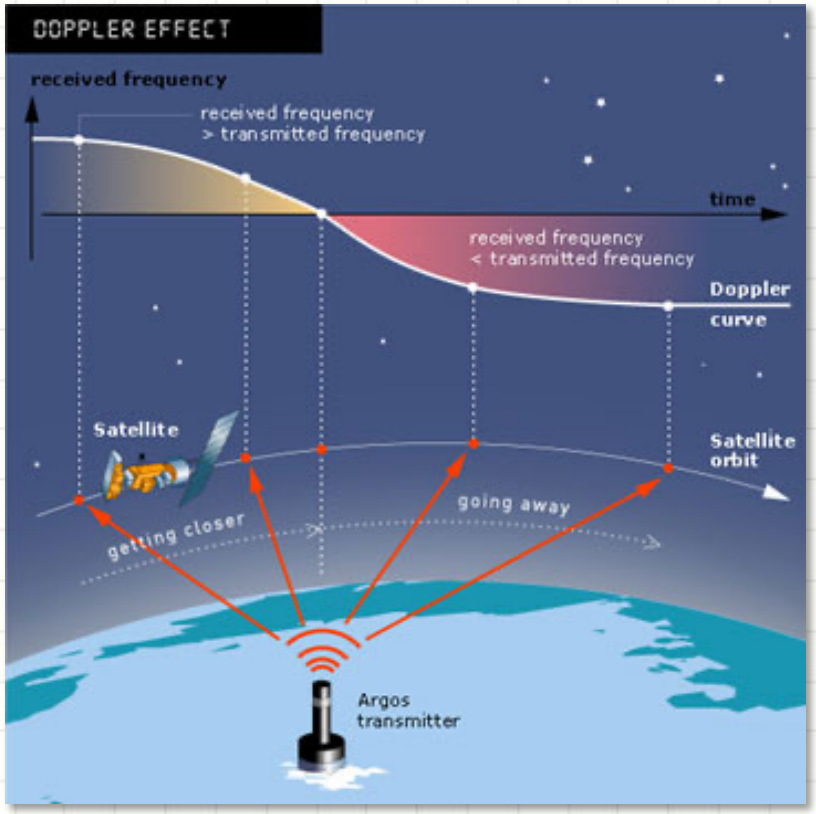
Polar LEO Satellite Orbit

Video on YouTube

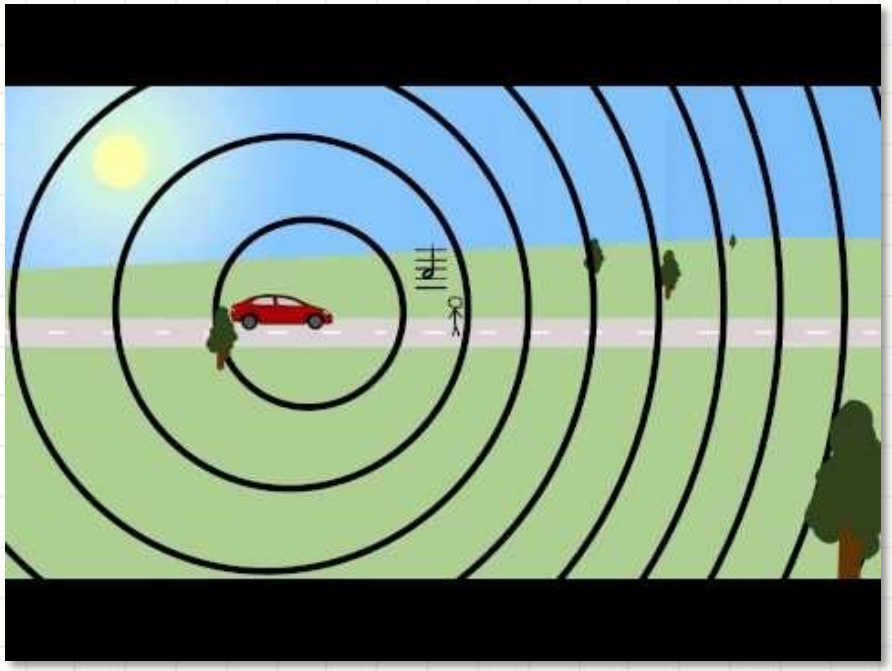
Covering the Earth

Satellite Doppler Shift

Changing Radio Frequencies



Radio waves sent from fast moving object also experience Doppler Shift



Basics of The Doppler Effect

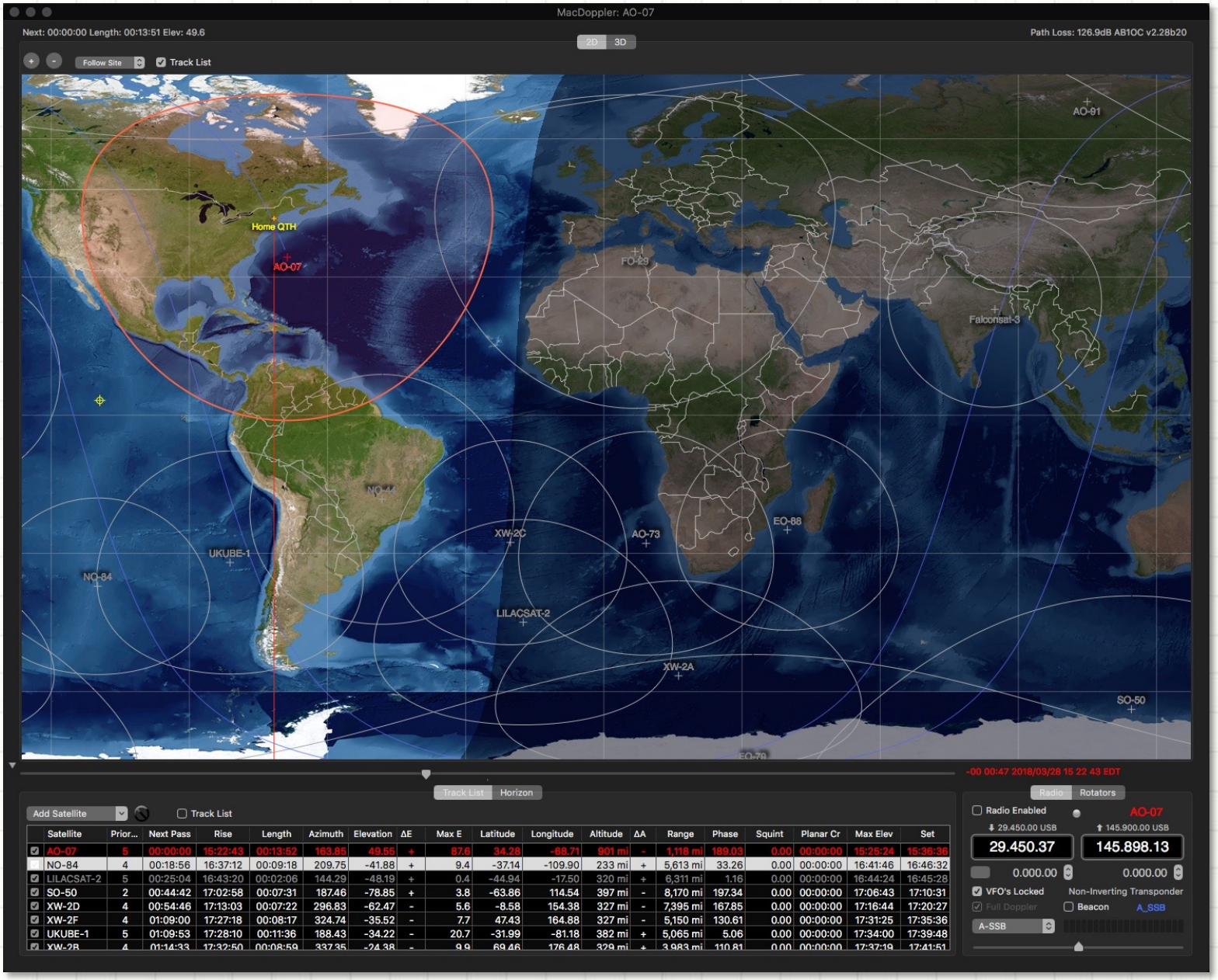
- LEO Satellites and the ISS are in low orbits and must move at high speeds
  - Typical orbital velocity ~= 17,100 mph or 4.8 miles/sec
- Doppler frequency shift is in the range of 10 – 30 KHz for UHF and higher links

Satellite Ground Station must adjust its transmit (uplink) and receive (downlink) radio frequencies to compensate for Doppler Shift.

Amateur Radio Space Ground Station

- Computer software tracks space objects & corrects doppler shift
- Amateur Radio Transceiver creates uplink & downlink)
- Audio Gear so we can listen and talk

Tracking Objects Using a Computer



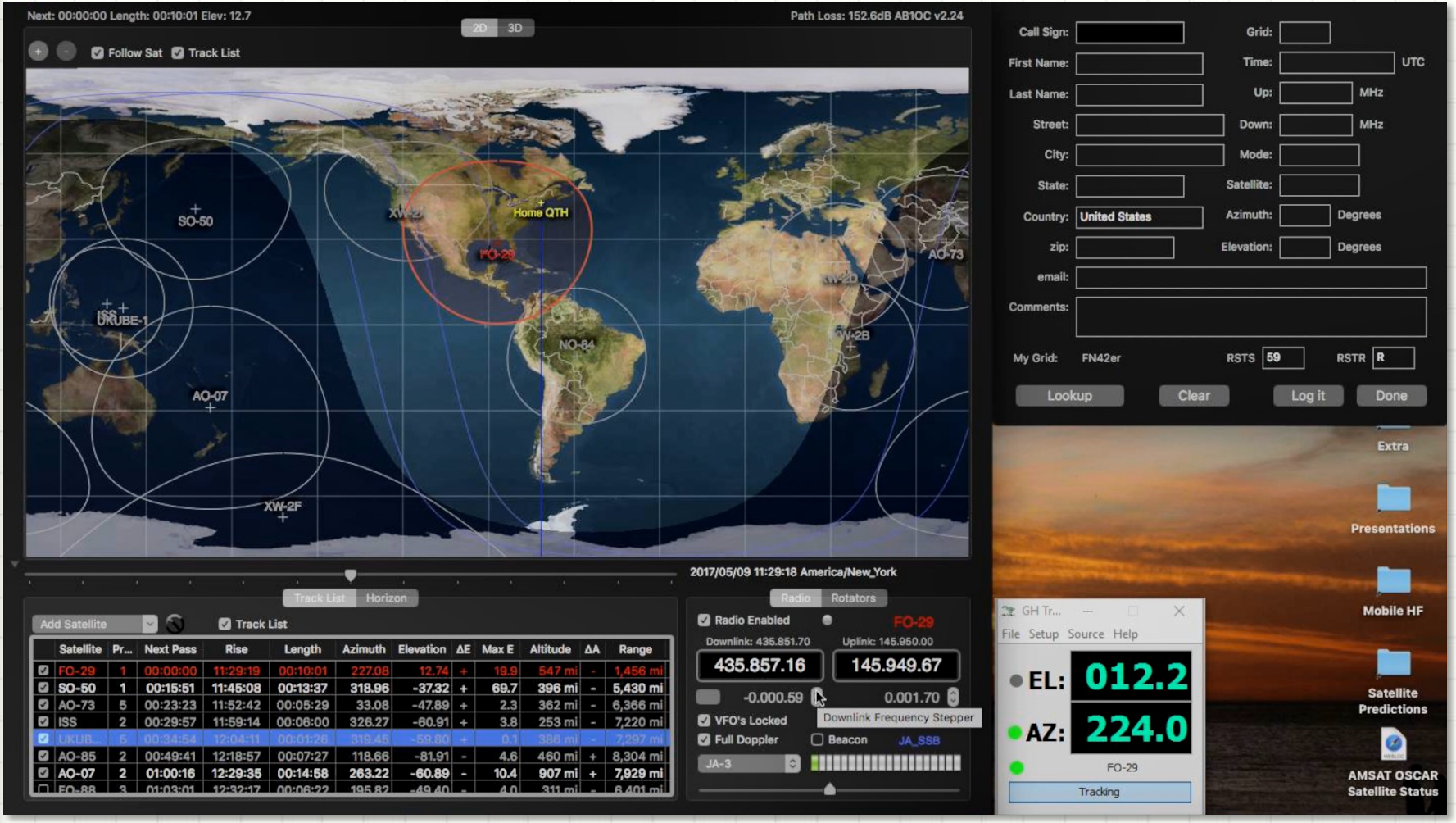
Satellite	Prior...	Next Pass	Rise	Length	Azimuth	Elevation	ΔE	Max E	Latitude	Longitude	Altitude	ΔA	Range	Phase	Squint	Planar Cr	Max Elev	Set
AO-07	5	00:00:00	15:22:43	00:13:52	163.85	49.55	+	87.6	34.28	-68.71	901 mi	-	1,118 mi	189.03	0.00	00:00:00	15:25:24	15:36:36
NO-84	4	00:18:56	16:37:12	00:09:18	209.75	-41.88	+	9.4	-37.14	-109.90	233 mi	+	5,613 mi	33.26	0.00	00:00:00	16:41:46	16:46:32
LILACSAT-2	5	00:25:04	16:43:20	00:02:06	144.29	-48.19	+	0.4	-44.94	-17.50	320 mi	+	6,311 mi	1.16	0.00	00:00:00	16:44:24	16:45:28
SO-50	2	00:44:42	17:02:58	00:07:31	187.46	-78.85	+	3.8	-63.86	114.54	397 mi	-	8,170 mi	197.34	0.00	00:00:00	17:06:43	17:10:31
XW-2D	4	00:54:46	17:13:03	00:07:22	296.83	-62.47	-	5.6	-8.58	154.38	327 mi	-	7,395 mi	167.85	0.00	00:00:00	17:16:44	17:20:27
XW-2F	4	01:09:00	17:27:18	00:08:17	324.74	-35.52	-	7.7	47.43	164.88	327 mi	-	5,150 mi	130.61	0.00	00:00:00	17:31:25	17:35:36
UKUBE-1	5	01:09:53	17:28:10	00:11:36	188.43	-34.22	-	20.7	-31.99	-81.18	382 mi	+	5,065 mi	5.06	0.00	00:00:00	17:34:00	17:39:48
XW-2B	4	01:14:33	17:32:50	00:08:59	337.35	-24.38	-	9.9	69.46	176.48	329 mi	+	3,983 mi	110.81	0.00	00:00:00	17:37:19	17:41:51

Space Communications

Computer Controlled Satellite Ground Station Operation

LEO Communications Satellite Demo

Linear Transponder Satellite FO-29



ISS Crew Contact Via Amateur Radio

Hudson Memorial School

[ISS Contact Video on Vimeo]

High Altitude Balloon Carrying Amateur Radio

Launching our HAB – Final preparations

Nashua Area Radio Society

N1FD

HAB Design Parameters

- Balloon Size: 1500 g
- Payload weight including parachute: 1040 g
- Positive Lift: 1150 g
- Burst altitude: 33,210 m a.s.l.
  (~ 108,900 ft. or ~20 mi)
- Required Helium: 133 cu. ft.
- Average Ascent Rate: 5.02 m/s
- Ascent time: 111 mins
- Descent time: 42 mins
- Final descent speed: 6.32 m/s (~ 14 mph)
- Total flight time: 153 mins (2 hrs and 35 mins)

These parameters are conservative and should keep our HAB's total flight time under 2-3/4 hours and our landing speed safe.

Update HAB's Flight Path Prediction

We'll use an online software package from a HAB prediction site: http://predict.habhub.org/

- Website starts you in the UK: Zoom out using mouse and move map to MA or NH
- Click ***Set With Map*** in order to use the mouse to click the balloon's starting point or use Lat/Lon coordinates
  - Winchester, NH elem. School: **Lat/Lon = 42.767896, -72.377026**
- Our ***Launch Altitude*** would be 145 m (from web)
- Select a ***Launch Time*** *(UTC)* and ***Launch Date***
  - Look UTC up online in case your unfamiliar
- Use results from High Altitude Science Balloon Calculator and feed into ***Ascent Rate*** and ***Burst Altitude***
- Use the parachute chart to estimate the ***Descent Rate***
- ***Run the Prediction!***

FAA Notification

Filing a NOTAM

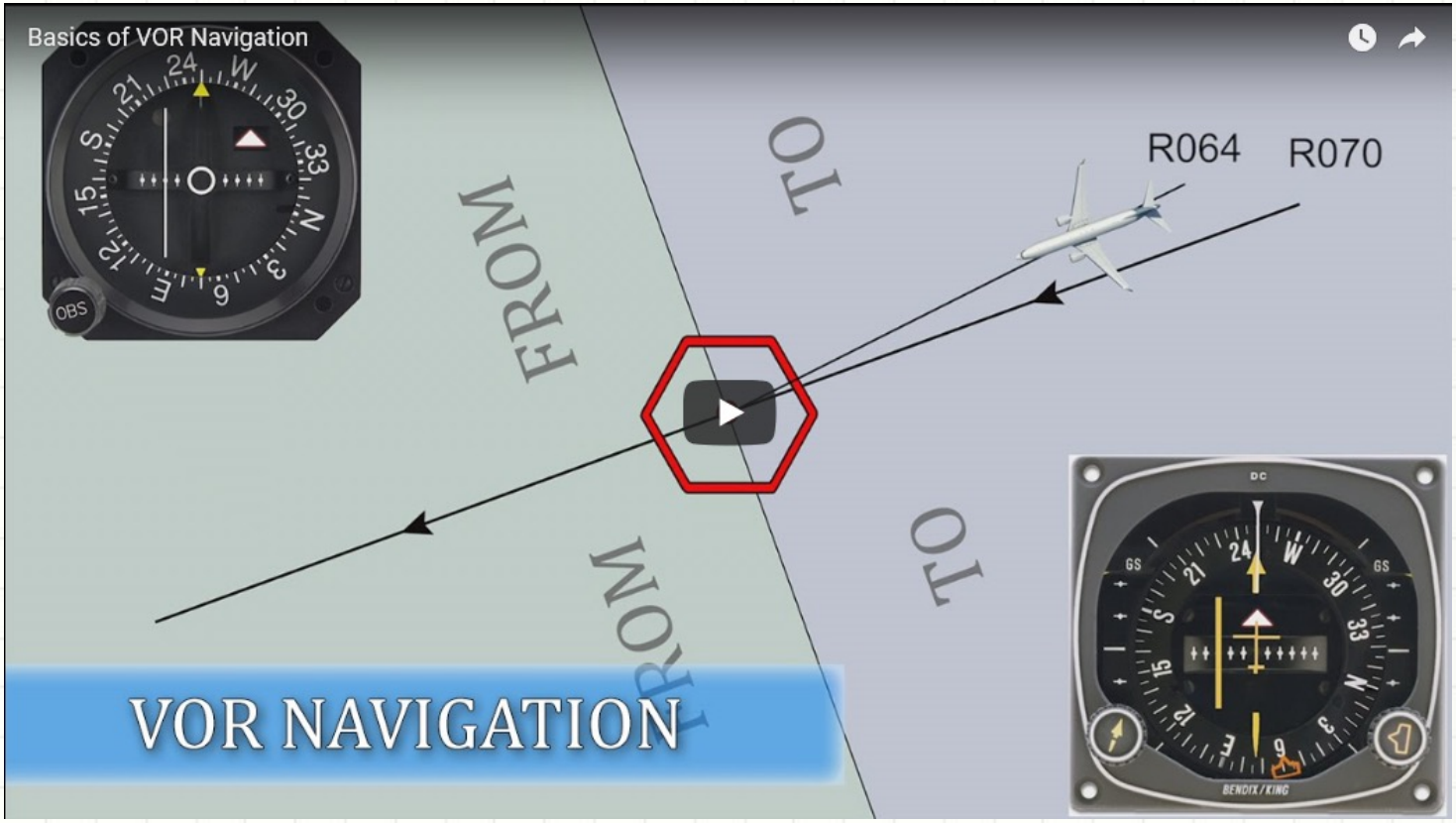
- Best to notify the FAA about our launch time and intended course
  - Do this by filing a NOTAM (Notice to Airman)
- Communicate our launch location based upon the nearest VOR Beacon (used for Airplane navigation)
- Sectional VOR navigations charts at - http://vfrmap.com/
  - Used by pilots to Navigate via VOR

VOR = Very high-frequency Omnidirectional Ranges. A radio navigation system used by pilots.

FAA Notification

How VOR Works

[How VOR Works Video]



VOR = Very high-frequency Omnidirectional Ranges. A radio navigation system used by pilots.

Example NOTAM

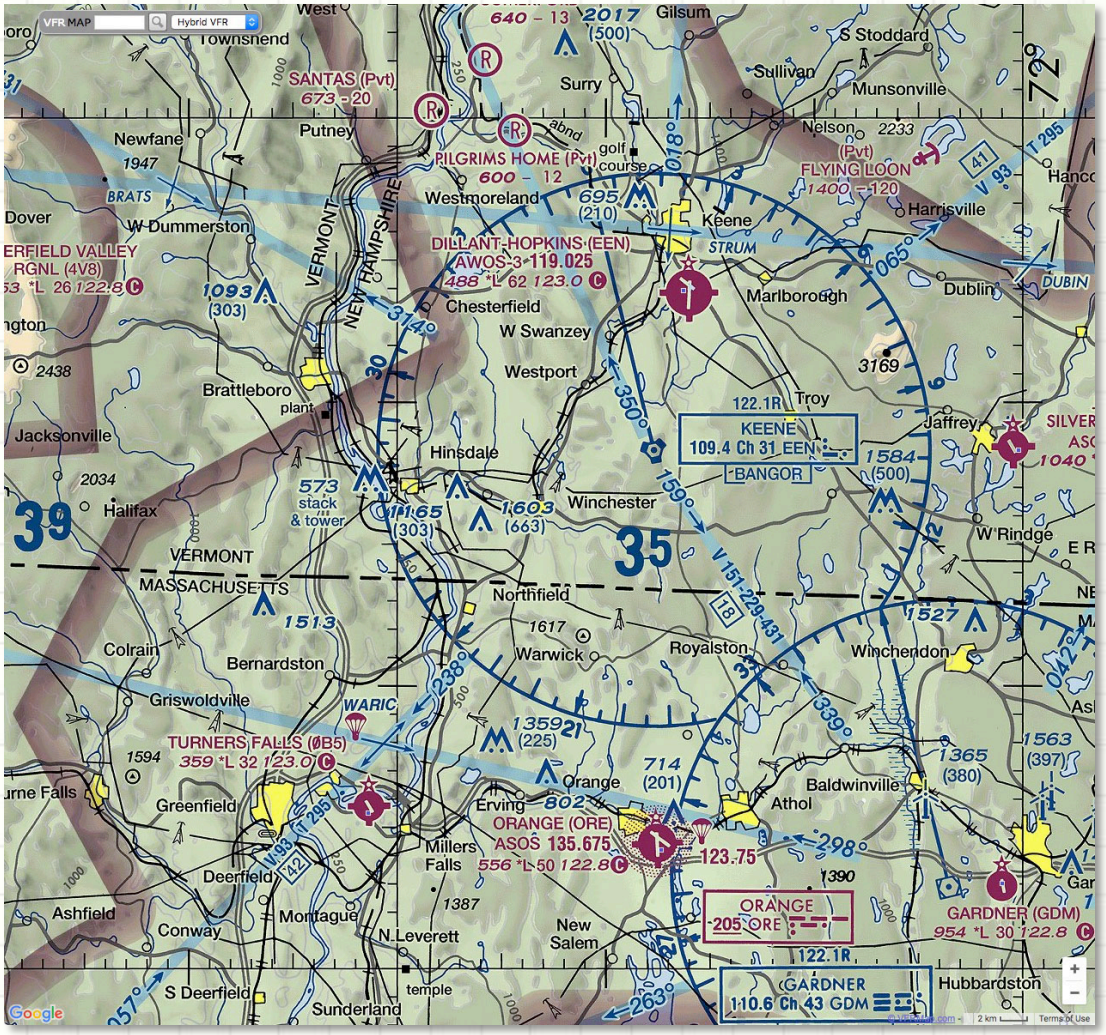
For Winchester, NH Launch Site

- We are filing a NOTAM for a “high-ball” ***[Weather Balloon]***
- Launching Echo-Echo-November VOR, radial two-six-zero, at 4.6 nautical miles”
- Launching April one-zero between one-four and one-five hundred zulu
- Estimated time to sixty thousand feet no later than one-six thirty zulu
- Estimated time of landing no later than one-eight hundred zulu
- Estimated flight trajectory of high-ball is North-East
- White balloon fifteen feet in diameter, red parachute, weighting 3 pounds
- Our contact information

Filing a NOTAM

Launch Location

- Closest VOR beacon is Keene, NH (Call sign E-E-N)
- Launch site heading from this VOR is 260°
- Distance from VOR beacon is approx. 8.6 km or 4.6 nautical miles
  - 1 km = 0.54 nautical mi.



"Launching Echo-Echo-November VOR, radial two-six-zero, at 4.6 nautical miles"

Filing a NOTAM

Key Flight Point Time Estimates

- "Launching April one-zero between one-four and one-five hundred zulu"
  - Launch will be on May 13th between 10 am and 11 am
  - To convert Local to Greenwich Mean Time (zulu): add 4 hours
  - 10 am = 14:00z and 11am = 15:00z
- "Estimated time to sixty thousand feet no later than one-six thirty zulu'
  - Worst case time to 60,000 feet of 90 minutes (16:30z) or 12:30 pm local time
- "Estimated time of landing no later than one-eight hundred zulu"
  - Worst case flight time is no more than 3 hours (18:00z) or 2 pm local time

Example NOTAM

For Winchester, NH Launch Site

- We are filing a NOTAM for a “high-ball” ***[Weather Balloon]***
- Launching Echo-Echo-November VOR, radial two-six-zero, at 4.6 nautical miles”
- Launching April one-zero between one-four and one-five hundred zulu
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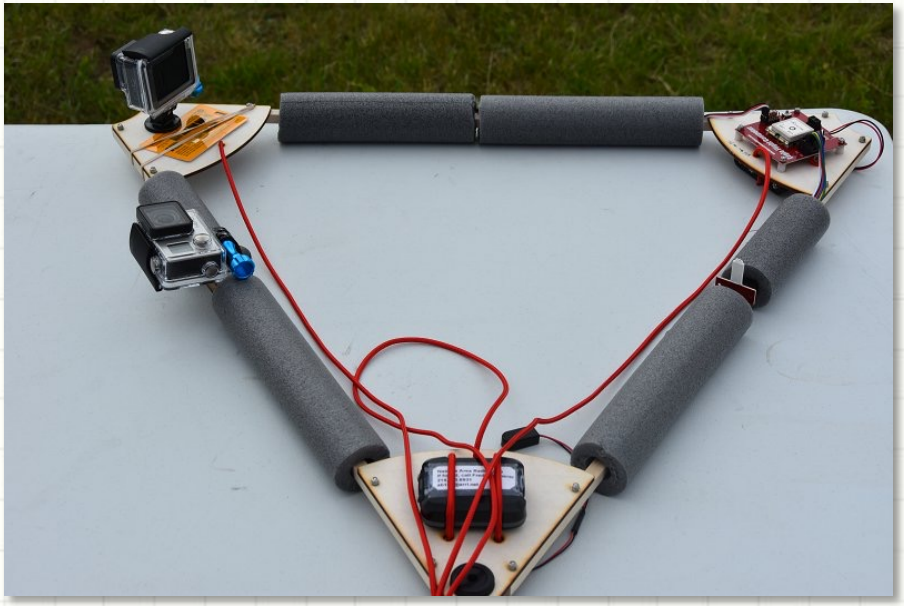
- Estimated time of landing no later than one-eight hundred zulu
- Estimated flight trajectory of high-ball is North-East
  - Based on final course prediction – will be NE, E, or SE
- White balloon fifteen feet in diameter, red parachute, weighting 3 pounds
- Our contact information

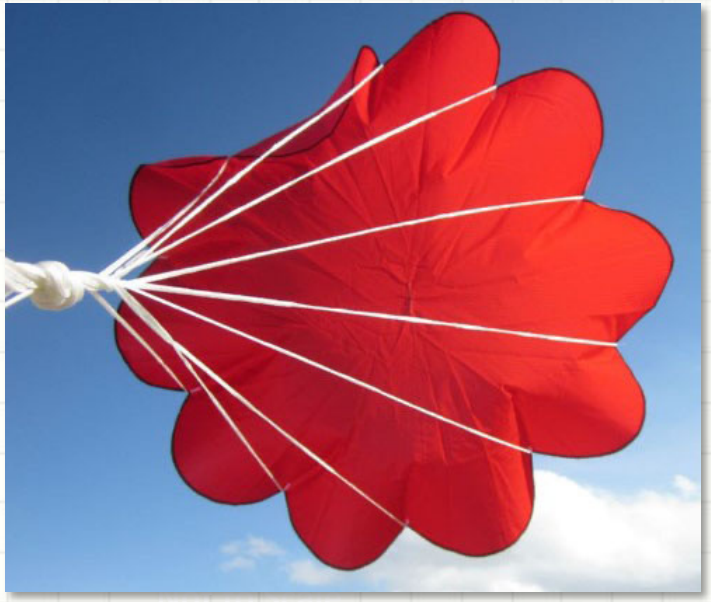
High Altitude Balloon

What is it?

HAB During Ascent

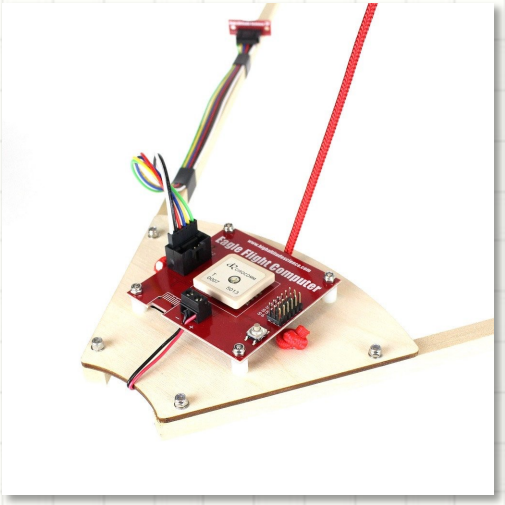


Flight Platform & Parachute



High Altitude Balloons

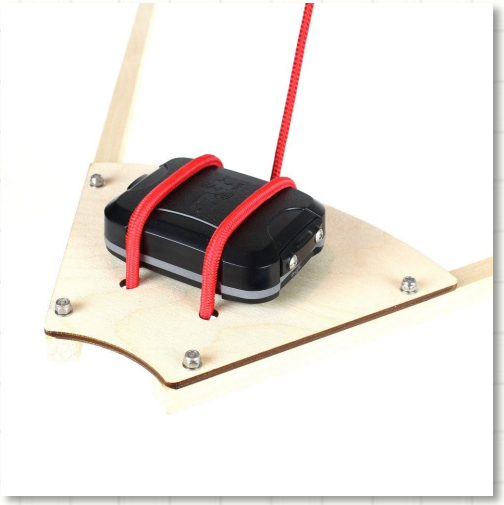
Payload Components



Flight Computer

GoPro Camera

APRS Radio Transmitter



Commercial Satellite Tracker

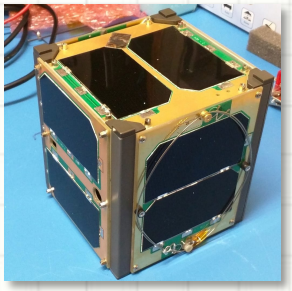
High Altitude Balloons

Flight Prep, Launch, Tracking, and Recovery

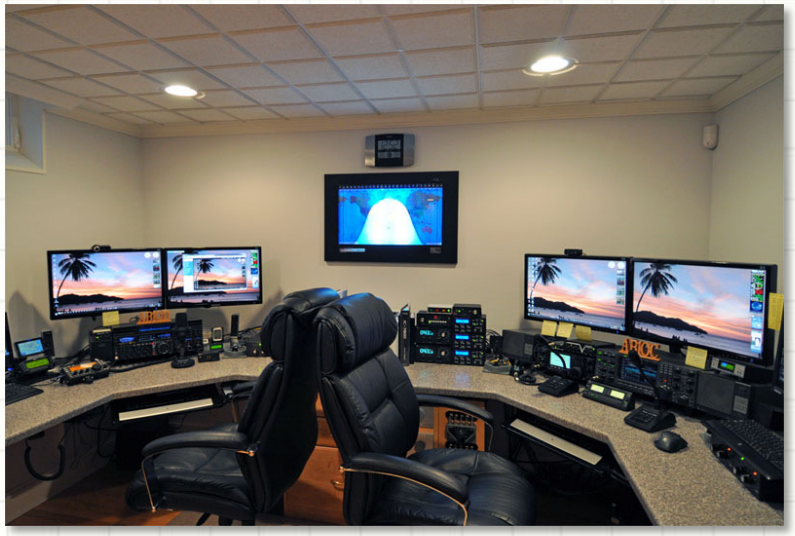
Vimeo link to HAB-2 video

Amateur Radio

Open House

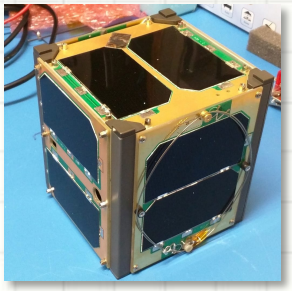


- Tour an active Amateur Radio station and learn more about amateur radio communications
- Get on the air and talk to Amateurs around the world
- Make a contact through a satellite in space
- Use Radio Direction Finding to locate a hidden radio transmitter
- See how we use computers in communications



Amateur Radio

Field Day – June 23rd & 24th



- Tour an Amateur Radio emergency communications installation
- Learn about antennas, radio equipment and gear
- Get on the air and talk to Amateurs across the USA
- Make a contact through a satellite in space
- Use Radio Direction Finding to locate a hidden radio transmitter
- See how we use computers in communications
- Field Day 2017 Video & Field Day 2016 Video

High Altitude Balloon Carrying Amateur Radio

Post-flight Data Analysis – The following is an example of what we'll be doing together

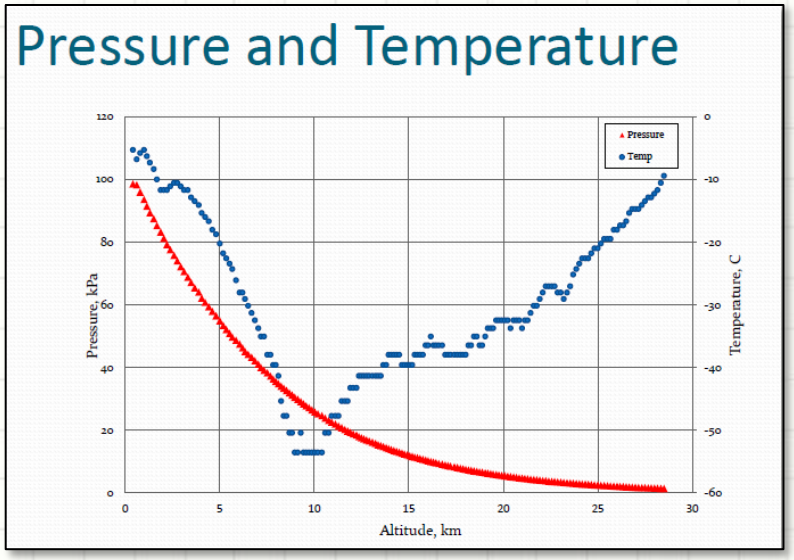
Nashua Area Radio Society

N1FD

Atmosphere Phenomena

What did our Flight Computer record?

- HAB's flight computer measured and recorded data about our flight:
  - ***Position, Heading and Speed***
  - ***Altitude***
  - ***Temperature and Pressure***
- Amateur Radio APRS Transmitter sent this data to ground



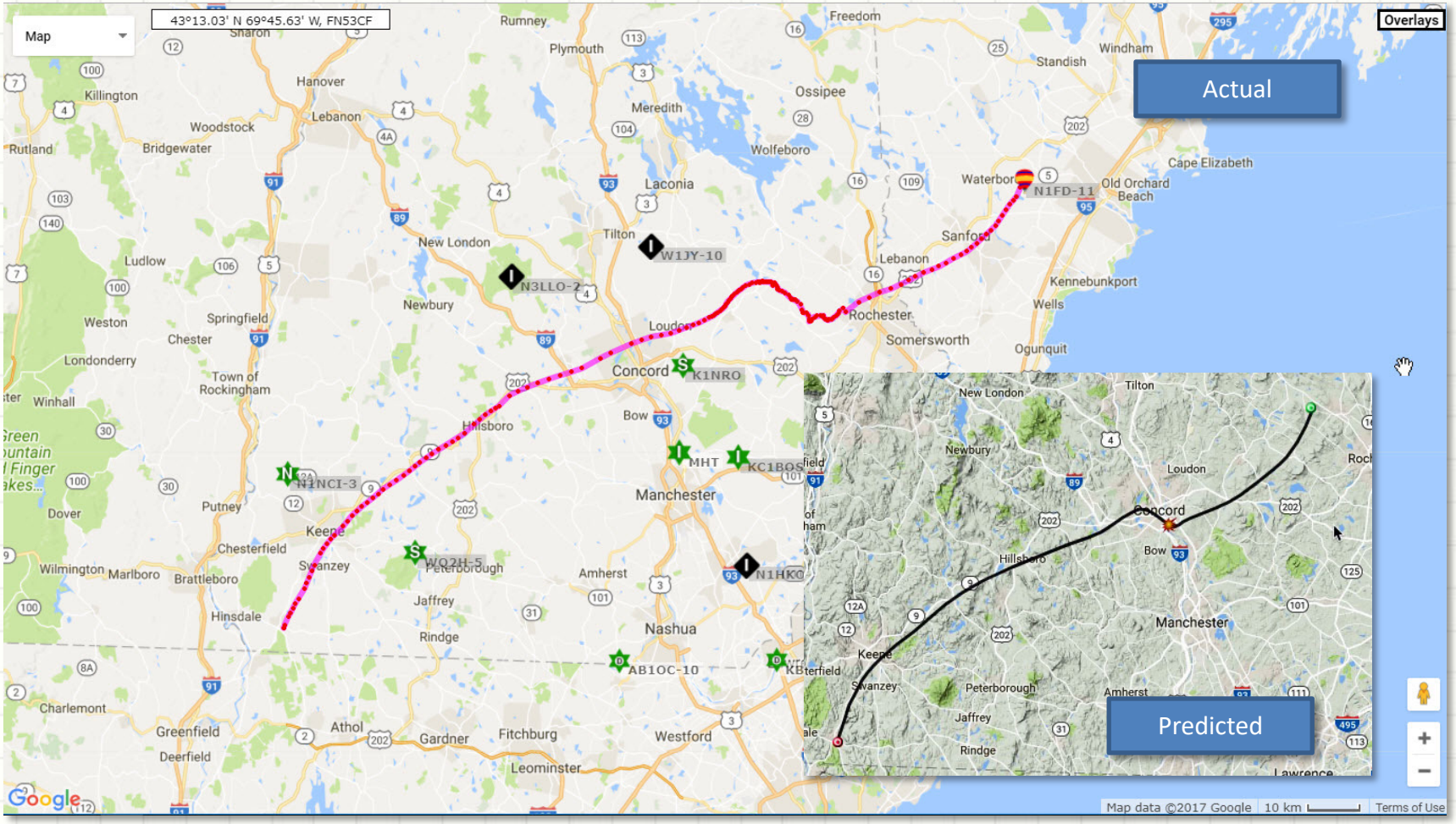
Actual HAB Flight Computer Data

```
Date     ,Time     ,Latitude  ,Longitude ,Head,Km/h,Alt-m  ,Lock,Temp C,Pa
10/28/17,17:36:42,+043.30393,-071.11218,0088,0027,+035939,0003,-001.4,000301
10/28/17,17:36:48,+043.30395,-071.11161,0083,0033,+035955,0003,-001.1,000073
10/28/17,17:36:54,+043.30419,-071.11113,0039,0027,+035811,0003,-001.6,000180
10/28/17,17:37:00,+043.30432,-071.11008,0082,0046,+035527,0003,-002.0,000580
```

We compared HAB flight data to our predictions to see how well they matched and we analyzed our data.

HAB-2 Flight Path

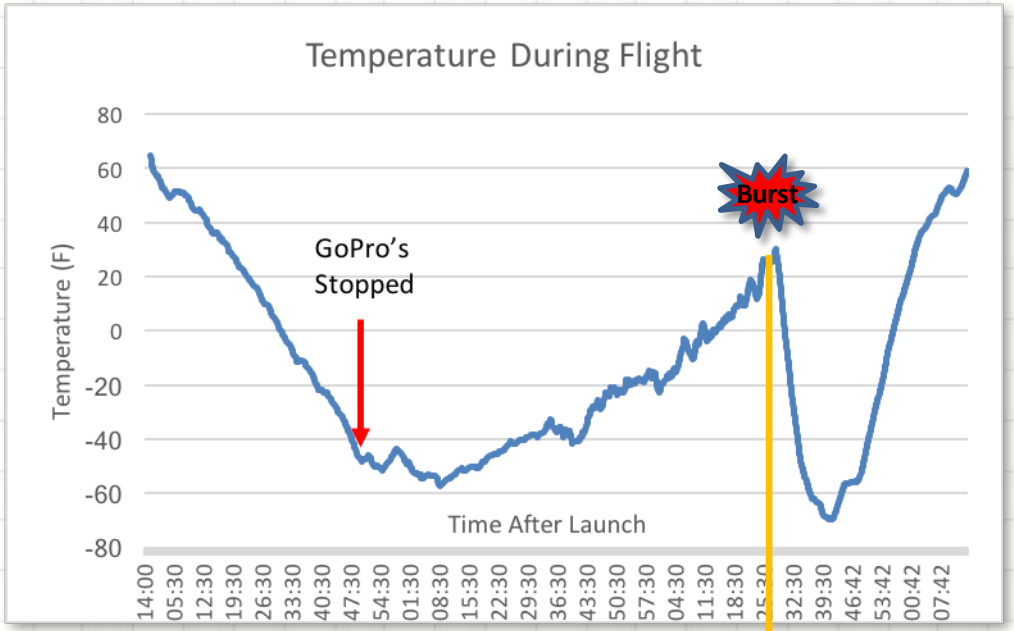
Actual vs. Predicted

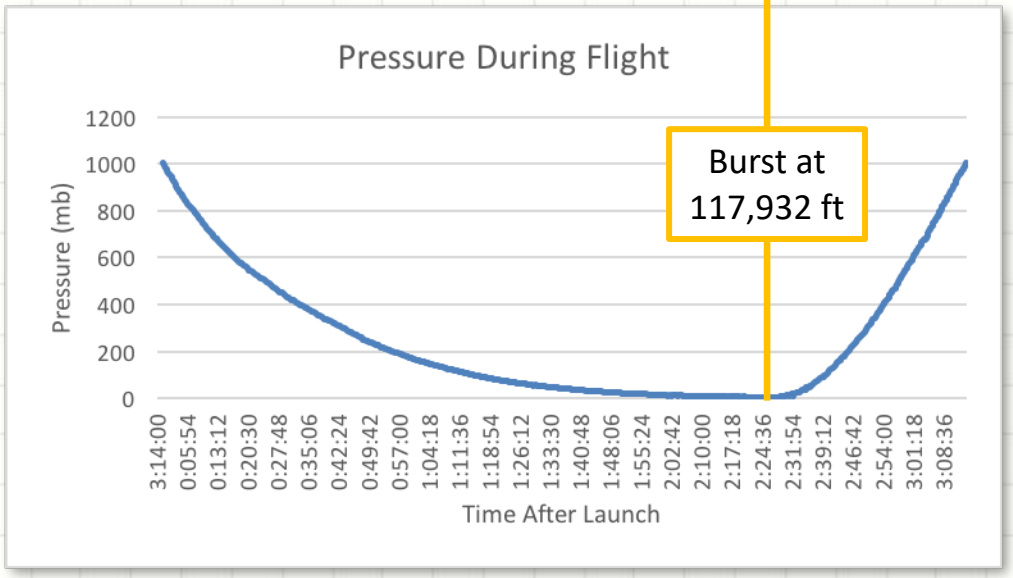


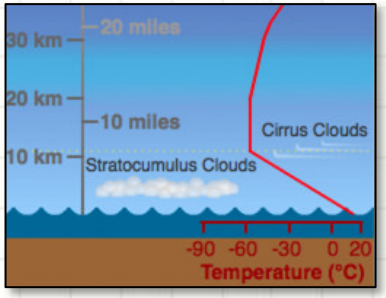
HAB-2 flew further, longer and higher than predicted –
Probably not quite enough Helium in the Balloon…
(Actual Burst Altitude was ~118,000 ft or ~ 22 mi)

HAB-2 Atmospheric Measurements

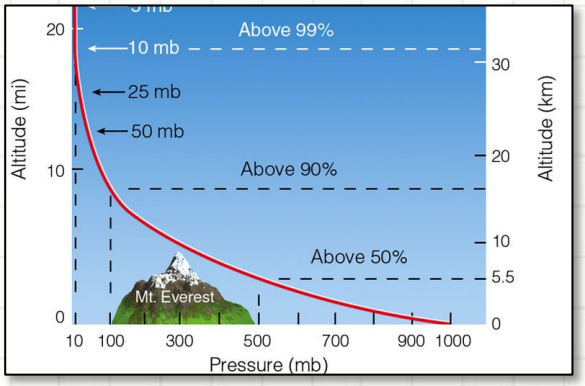
Temperature and Pressure







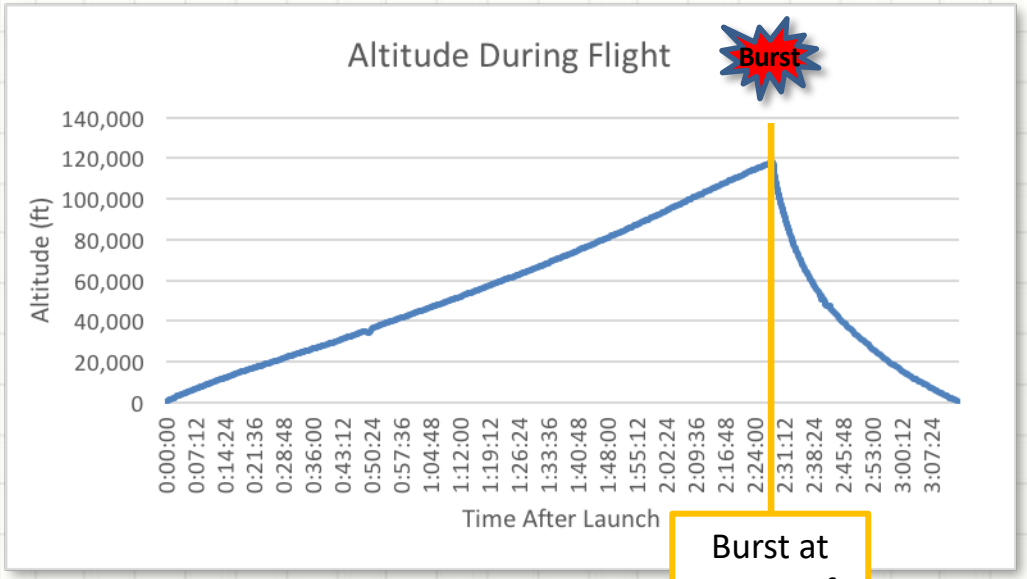
- Very cold temperatures on ascent (-57°F) & descent (-70°F)
- Cameras shutoff at around 40,000 ft due to low temperature
- Shape of temperature changes was as expected



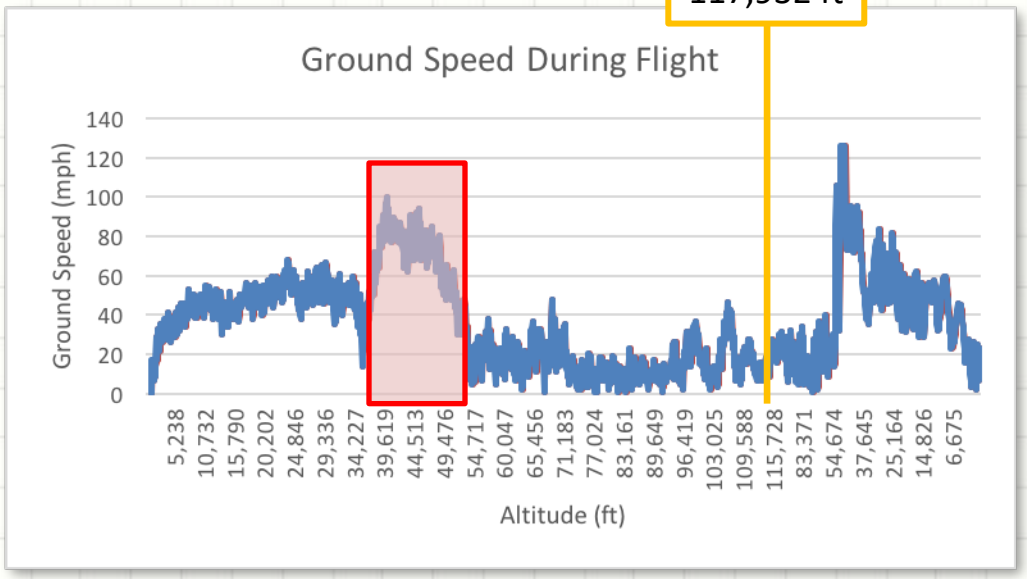
- Measured pressure was as we expected

HAB-2 Speed Measurements

Ground and Descent Speed



Burst at 117,932 ft



- Ascent rate did not change much between launch and burst
- Jetstream winds increased ground speed significantly
  - ~35,000 – 50,000 ft
  - Max of ~100 mph!
- Not enough air above 50,000 ft to move HAB-2 along ground
- Descent after burst was very rapid until about 50,000 ft

Date	Time (UTC)	Time After Launch	Ground Speed (mph)	Altitude (ft)	Ascent/ Descent Rate (mph)	Notes
10/28/17	18:21:54	3:13:24	25	954	-12	
10/28/17	18:22:00	3:13:30	22	859	-11	500 AGL
10/28/17	18:22:06	3:13:36	7	768	-10	
10/28/17	18:22:12	3:13:42	7	666	-12	
10/28/17	18:22:18	3:13:48	15	567	-11	200 ft AGL
10/28/17	18:22:24	3:13:54	23	469	-11	
10/28/17	18:22:30	3:14:00	19	351	-13	Touchdown!

- Parachute descent rate was about 12 mph at landing
  - About what we expected

BACKUPS AND OLD SLIDES

Our Sessions

Weekly One-Hour Format

1. A: Project Introduction – What will we be doing?
2. B: Balloon Physics 1 – Forces effecting our HAB's flight and burst altitude
3. C: Balloon Physics 2 – HAB's weight and burst altitude revisited
4. D: The Atmosphere – Temperature and Pressure our HAB will encounter
5. E: Descent through the Atmosphere – Parachute operation
6. F: HAB Flight Path Prediction – It's mostly about the Jetstream
7. G: HAB Tracking and Radios 1 – Following our HAB and its data
8. H: HAB Tracking and Radios 2 – Hands on with Tracking Tools
9. I: Space Communications – What's up & how do we communicate using it?
10. J: Launching Our HAB – Final preparations
11. K: Post-flight Data Analysis
12. L: Preparing Our Project Report

Will include a variety of Hands-on Activities and Demos

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4. G: HAB Tracking and Radios 1 – Following our HAB and its data
   H: HAB Tracking and Radios 2 – Hands on with Tracking Tools
5. I: Space Communications – What's up & how do we communicate using it?
   Second Hour would involve hands-on use of space comms. ground station
6. J: Launching Our HAB – Final preparations (classroom or during Open House?)
   Amateur Radio Open House
7. K: Post-flight Data Analysis (may be two, 1 hour sessions…)
   L: Preparing Our Project Report

Will include a variety of Hands-on Activities and Demos

Demonstrations and Hands-on Activities

Demo	Purpose	HAB Class Session	Instructor Equipment	Classroom Support
HAB Platform and Components	See and understand HAB Platform and Balloon	Sec. A, Sec. E (Parachute), Sec. J	Platform, Camera, Equipment, and Balloons	None
HAM Radio Distant (DX) Contacts	Introduce Ham Radio DX Contacts	First or second and subsequent	Remote HF Radio System, QSL Card Books	Internet/WiFi and AC power
Electromagnetic Spectrum (EMS)	Understand the EMS and where HAM Radio & the HAB fit	First or second	RF Spectrum Roll, EMS Handouts	None
Buoyancy Demo	Demonstrate Archimedes Principal	Sec. B – Balloon Physics 1	Beaker, Gram Weight, Ice, Water	None
HAB Flight Modeling	Apply Physics and Weather to predict the HAB's flight path	Sec. B, F, and J	Data for calculators	Student Computers with Internet Access
Weighting HAB Components	Measure weight of HAB Platform	Sec. C – Balloon Physics 2	Hanging scale, check weights, cal. water bottle	Calibrated gram scales, place to hang scale
Communicating via Morse Code	Understand methods for comm. in marginal conditions	TBD	Practice oscillators/keys, Morse Code Charts	None
HAM Radio Local Contacts	Understand local Ham Radio Contacts & Emergency Comms.	TBD	Handy Talkies, Emergency Go Kit w/antenna	Location that is not RF blocked, AC power
Electronic Circuit Experiments & Construction	Introduce experimental electronics construction and design	TBD	PIXIE CW Trans, Oscilloscope Kit, KX2, Touch CW Paddles, other home built projects	AC Power, Internet/WiFi
Radio Direction Finding (RDF)	Understand RDF for emergency and compliance purposes	TBD	Handy Talkies, Directional Antennas, Fox Transmitters	"Hide" transmitter in classroom
Transmit Antennas	Understand radio transmitter antenna systems	TBD	Buddipole ant., dummy load, KX3, SWR meter	Space in classroom to setup ants., AC power
Ham Radio Contacts through Satellites	Experience and learn about Space Communications	Sec. I – Space Comms. or Open House	Portable Satellite Ground Station, Satellite, pass predictions	Loc. with outside access to setup equip., AC power & Internet/WiFi

Our Sessions

Some things we'll need

- HDMI Connection to projector with audio for classroom sessions
- Internet Access - Will need unblocked access for presenter's PC and radio gear. The following are the MAC addresses:
  - Windows Laptop Mac Address C8-FF-28-3C-B1-E7
  - Backup Laptop Mac Address 48-51-B7-7D-7E-A9
  - MacBook Air Mac Address 34-36-3B-5D-DB-08
  - Remote Radio #1 Mac Address A0-C5-89-05-59-56
  - Remote Radio #2 Mac Address 88-12-4E-15-FA-0C
  - ISS/Satellite Antenna Controller Mac Address B8-27-EB-D1-27-C8
- Access to laptop's with Internet access for students to use during some of our sessions
  - Expect we'll want them to work in groups…
  - See table which follows for details
- Gram scales for our second session together would be helpful.
- We'll want to work through plans to test our space communications ground station at your school

These items will allow us to support Video Presentations, Hands-on Activities, and Demos

Air Density in the Atmosphere

Density

- Use gas-specific form of Ideal Gas Law:

$$PV = mR_{gas}T$$

- Solve for m/V:

$$\frac{m}{V} = \rho = \frac{P}{R_{gas}T}$$

- **Density can be shown to decrease with increasing altitude due to how pressure and temperature vary with altitude in previous chart**

Terminal Velocity Formula

Terminal velocity occurs when the object no longer accelerates.

$$F_{\text{net}} = mg - F_{\text{D}} = ma = 0.$$

When acceleration is zero, the force of gravity (mg) balances the drag force (F_D)

$$mg = F_{\text{D}}.$$

Substitute in the drag force equation

$$mg = \frac{1}{2}\rho C A v^2.$$

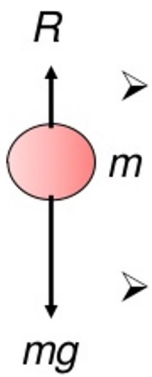
Solve for the speed (v) which is the terminal velocity. Because the HAB is going so high, the density of air is always changing.

$$v = \sqrt{\frac{2mg}{\rho C A}}.$$

The Air Drag Force

** Air Resistance (drag force)

- It's the friction force on an object moving through air (or a fluid)



- Although we often ignore air resistance (***R)***, it is usually significant in real life.

- ***R*** depends on:
  - Speed (directly proportional to v^2).
  - cross-sectional area
  - air density
  - other factors like shape

Drag Force Equation

$$F_D = \frac{1}{2}\rho C A v^2$$

- The Greek letter *rho* is the air density
- *C* is the drag coefficient
- *A* is the area
- *v* is the speed