High Altitude Balloon Flight Predictions

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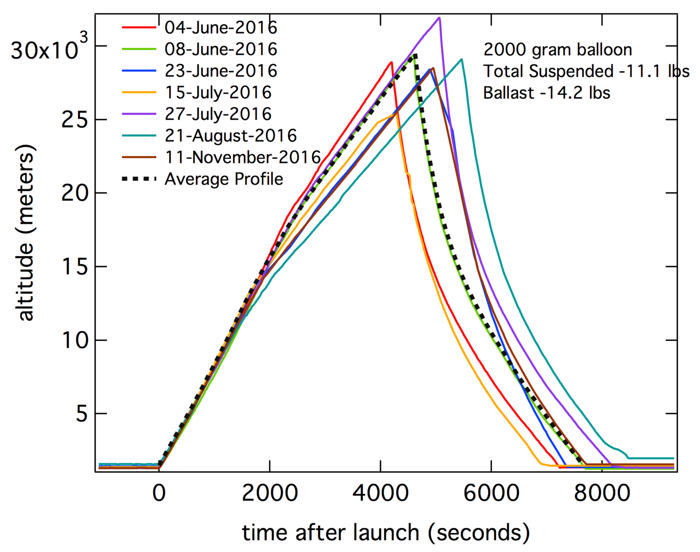
ABSTRACT

Flight trajectory predictions are critical for high altitude balloon operations to ensure safety and ease the recovery of payloads. They provide the HAB team with the information needed to choose the optimal launch time, date, and location to maximize the chances of a successful flight. Although no method achieves perfect accuracy, several free programs exist which are user friendly even for those new to high altitude ballooning and which yield acceptable predictions.

TYPICAL FLIGHT PROFILE DATA



$$V = \sqrt{\frac{2 * W}{C_d * d_{air} * A}}$$

Equation for descent velocity under a parachute.

W = payload weight

C_d = drag coefficient for parachute

d_{air} = air density (varies with altitude: see US Standard Atmosphere)

A = area of the parachute

Altitude	'Ascent Rate'	'Descent Rate'
1500	6.3	-4.9
2500	6.5	-5.0
3500	6.6	-5.1
4500	6.8	-5.2
5500	6.9	-5.3
6500	7.0	-5.5
7500	7.2	-6.0
8500	7.2	-6.1
9500	7.4	-6.2
10500	7.5	-6.6
11500	7.7	-7.0
12500	7.8	-7.6
13500	7.2	-8.5
14500	6.8	-9.5
15500	6.6	-11.0
16500	6.3	-12.2
17500	6.0	-13.5
18500	5.7	-15.0
19500	5.5	-17.0
20500	5.3	-18.5
21500	5.2	-20.0
22500	5.1	-22.0
23500	5.0	-24.0
24500	5.0	-26.0
25500	5.0	-28.0
26500	4.9	-31.0
27500	4.9	-34.0
28500	4.9	-37.0
29500	4.9	-40.0

[Top and right] Data from a series of flights conducted using the standard MSU-BOREALIS eclipse balloon payload and a lift of 28%. Ballast is equal to the weight of the Helium fill valve plus the water bottles used to simulate payload weight.

To obtain a reasonably accurate prediction it is necessary to have some data about the typical ascent and descent rates for the balloon and payload that will be flown.

It is clear from the data and graphs shown that the ascent and descent rates of the balloons are not a single constant value, but each flight profile has a similar "sharkfin" shape with two distinct approximately linear ascent rates. While the rate of ascent is nearly constant in the troposphere for identical balloons (same size and shape, payload weight) it is more variable in the stratosphere. The size and shape of the parachute primarily influences the descent rate. With data from several flights, an average profile can be created with expected ascent/descent rates at various altitudes.

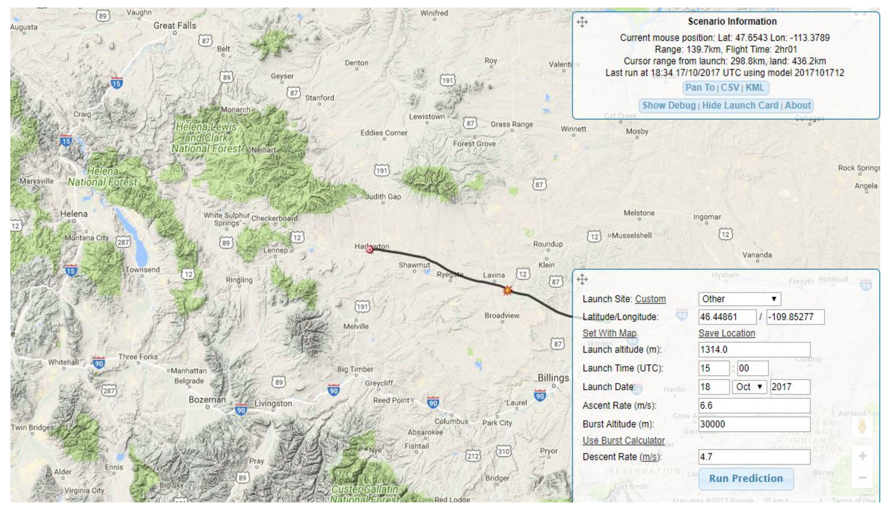
Ascent rate calculators:
http://habhub.org/calc/
https://www.highaltitudescience.com/pages/balloon-performance-calculator

CUSF LANDING PREDICTOR

A flight prediction program designed by Cambridge University Spaceflight, available as a web app (no download) at: http://predict.habhub.org

Program Inputs:

- Single ascent and descent rate (value at sea level)
- Launch time/date/location
- Launch altitude
- Expected burst altitude



Screenshot of CUSF website with input box. Trajectory plot can be imported into Google Earth for ease of viewing.

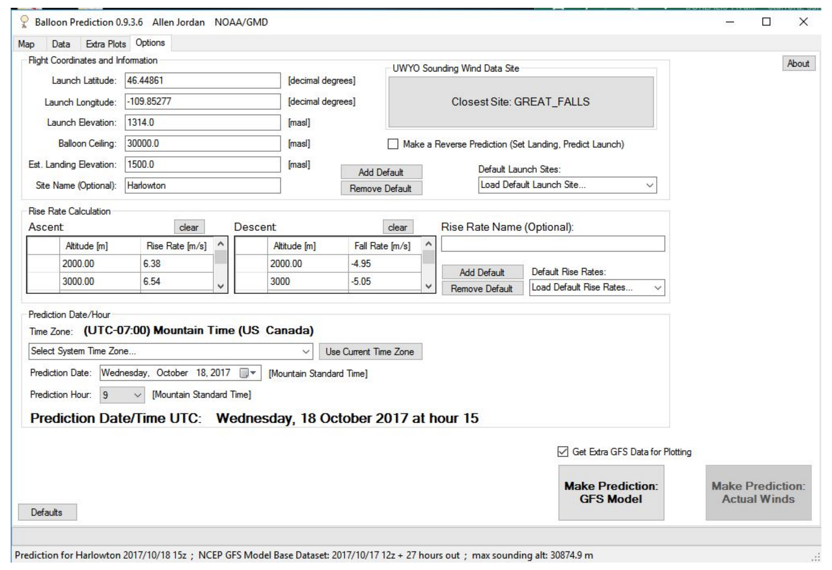
ALLEN JORDAN'S FLIGHT PREDICTOR

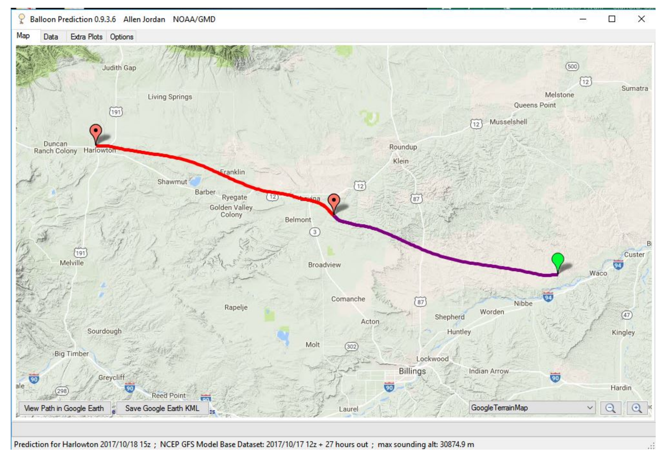
Software written for NOAA balloon flight predictions and available for free download from: http://www.allenjordan.info/balloonprediction.html

Program inputs:

- Variable ascent/descent rates
- Launch time/date/location
- Burst altitude
- Launch elevation
- Estimated landing elevation

Note: descent velocities as a function of altitude can be computed using the equation shown to the left.

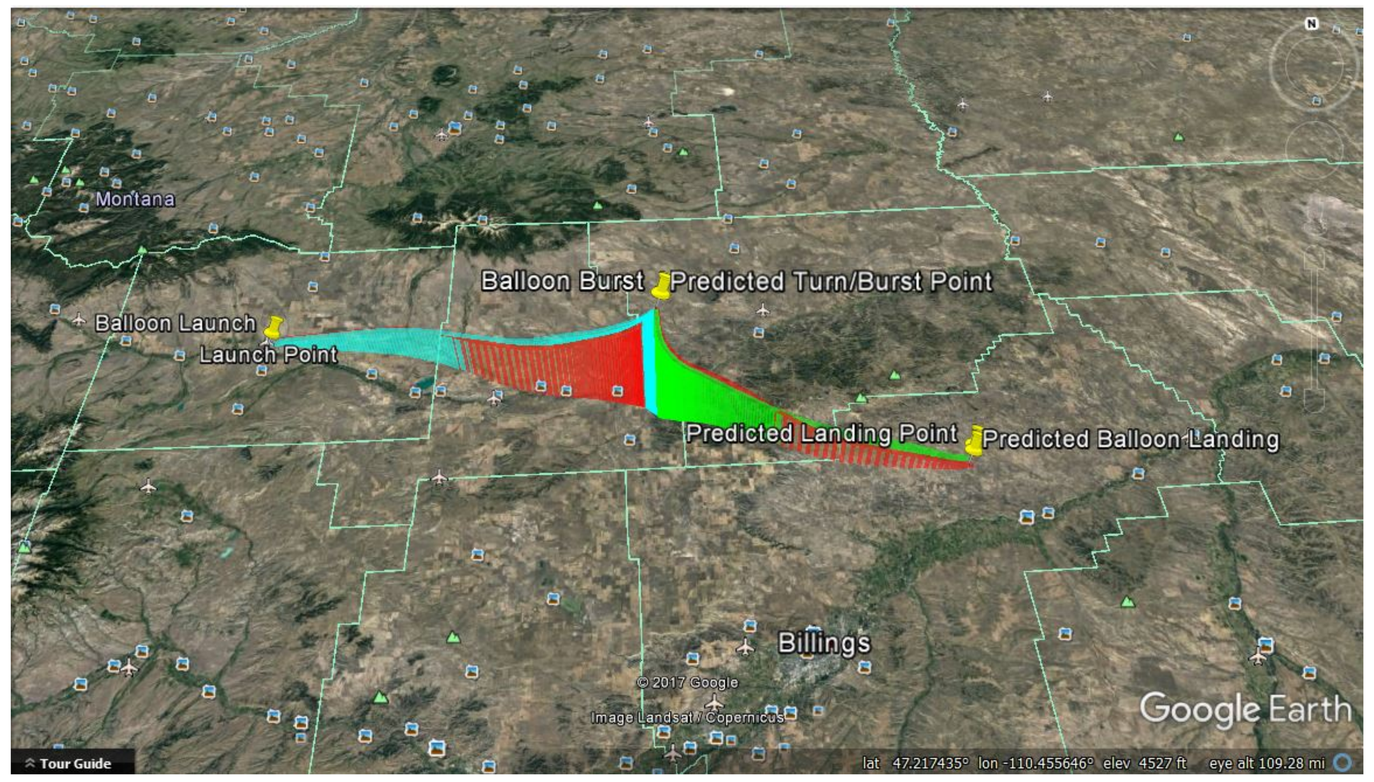




Input box (top) and trajectory plot (left) for Jordan program. Like the CUSF program, the output can be downloaded as a KML file and imported into Google Earth to better analyze the prediction laid over satellite terrain imagery.

COMPARISON OF PROGRAMS

There are other programs available for balloon flight predictions, but the two listed here are commonly used and have the benefit of being available to anyone for free download. The CUSF predictor is the simplest, with the least amount of input data and options, although it is limited by the constant ascent and descent rates. The NOAA software allows the user to change the altitude vs ascent/descent rate to obtain a slightly more accurate prediction. In practice, the two programs can produce virtually identical flight predictions if the user has enough data from previous flights to produce accurate average values.

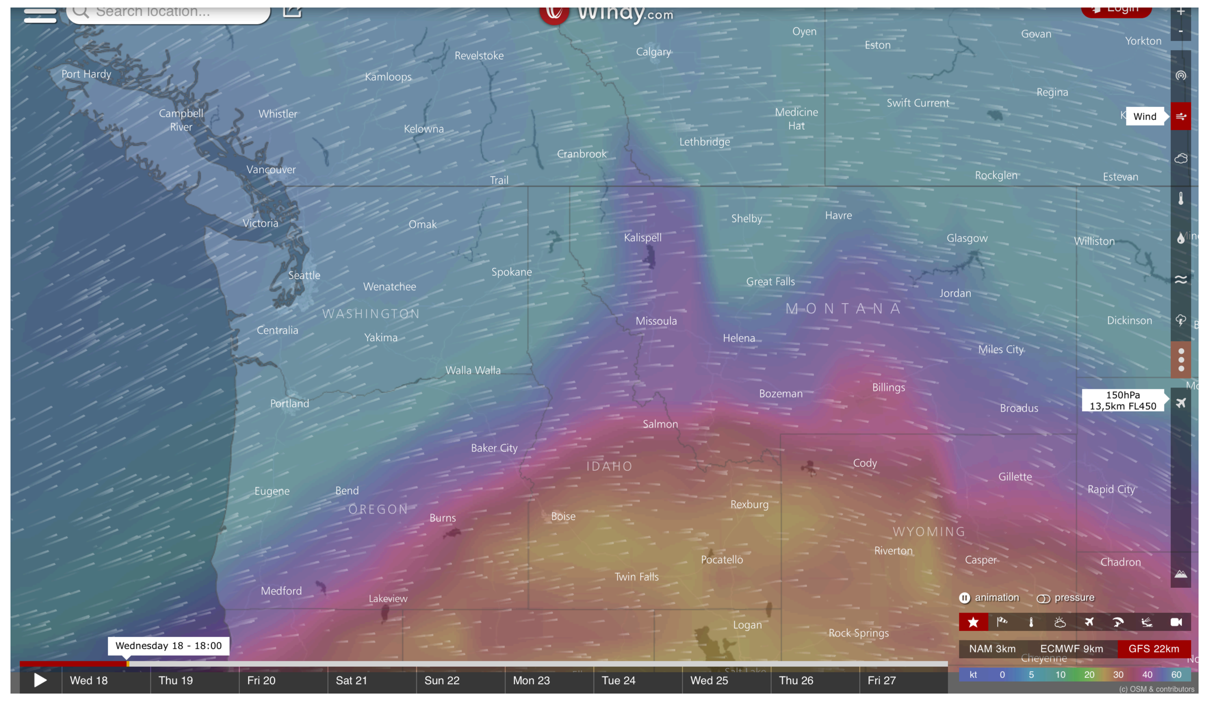


One flight prediction from NOAA program (blue/yellow) superimposed on the equivalent prediction from CUSF program (red).

STABILITY OF PREDICTION

After running a flight prediction, it is useful to have a method of assessing its reliability before making the decision to launch a balloon at a particular date and time. One simple way of doing this is to compare weather forecasts at different dates and times around the expected launch to determine stability. If the forecasted upper level winds do not vary significantly 24 hours before and after the launch time, it is reasonable to assume the prediction is reliable. If, however, the wind speed and direction varies greatly around the intended launch period the user should be more cautious.

In addition to looking at times/dates around the launch, different weather prediction models can be compared to determine stability. Both the CUSF and NOAA programs utilize data from the GFS (Global Forecast System) weather model. Two other weather prediction models, the NAM (North American Model) and ECMWF (European model) are commonly used.



Screenshot from Windy.com, a free weather prediction site that allows the user to visualize a variety of weather data, including wind velocity at varying altitudes up to 45,000'

CONCLUSIONS

- A variety of free resources are available to make flight predictions that are accurate enough for most purposes
- Nearly identical predictions can be obtained in both programs with good average ascent/descent rate data
- Analysis of weather prediction stability allows the user to judge the relative accuracy of the flight prediction

[Right] Comparison of a flight prediction (red) with two actual balloon flight trajectories (green and yellow) from the same launch time and location. The actual flight path deviates from the prediction somewhat but the predicted landing is within five miles of the actual landing point.