Balloon Flight Analysis

Weight

Meteorological Balloons

Balloon Type	1	2	3
Scientific Sales model #	-	8237	8244
Edmund Scientific order #	30665-68	-	-
Cost	$19	?	$72
Nominal Inflation diameter	4 ft	5 ft	6.3 ft
����������� Volume	33 ft^3	65 ft^3	130 ft^3
Bursting Inflation diameter	8 ft	13 ft	30 ft
����������� Volume	270 ft^3	1100 ft^3	14,000 ft^3
Mass of Balloon	110 g	300 g	1200 g
Weight of Balloon	1 N	3 N	12 N

Lift of Helium in std. air = 32 g/ft^3 = 0.31 N/ft^3 = 11 N/m^3 of vol.

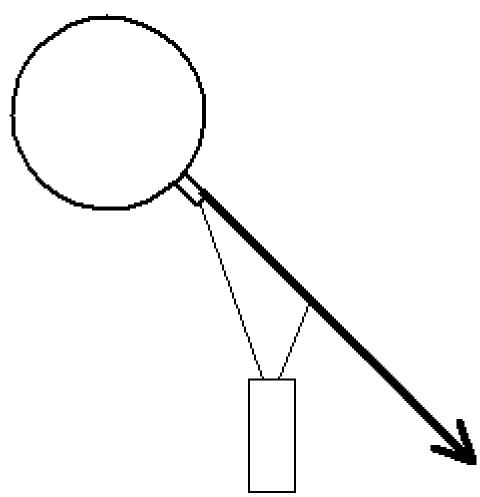
A common 4 ft cylinder of helium contains 244 ft^3 at 2490 psig and 70� F.� This implies that the cylinder has a volume of 1.43 ft^3.�
Assuming constant temperature: PV = constant

$$\Delta P = \frac{V}{1.43\, ft^3} 14.7 \frac{psi}{ft^3}$$

Every 10 ft^3 will use up about 103 psi for this size cylinder.

Flight String

150 #-test braided nylon twine weighs 350g / 1000ft.
μ = **0.350 g/ft (9.8N/1000g) = 0.0034 N/ft**
$F_w = \mu L$



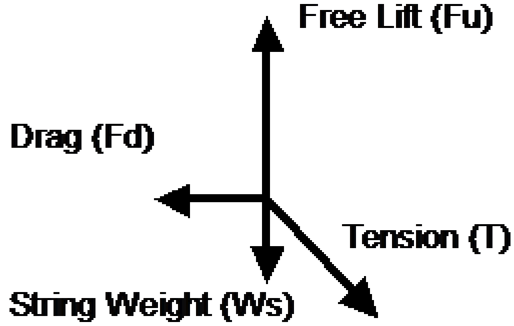
Gondola & Rig

Gondola	**500 g**
Picavet rigging & hang-up	**50 g**
LabPro (w/batteries)	**400 g**
Barometer (or other sensor)	**100 g**
Temp probe (SS)	**50 g**
Camera & Intervalometer	**<u>350 g</u>**
W_g =	**1450 g**

Forces

Drag

$F_d = ½\, C_d\, \rho\, V^2 A$
C_d = coefficient of drag ≈ 0.5
ρ = density of air = 1.23 kg/m^3
V = air speed (1 knot = 0.514 m/s)
A = cross sectional area = πr^2
$F_d = ½\, C_d\, \rho\, \pi\, V^2\, (0.514 m/s/knot)^2\, r^2\, (1m/3.28ft)^2$
$= k_1 V^2 r^2$
k_1 = 0.23 N/(knot ft)^2



Free Lift

F_u = Lift due to Helium less weight of balloon & gondola
F_u = 31.7 g/ ft^3 �V � W = k_2 r^3 � W
k_2 = 133 g/ft^3 = 1.3 N/ft^3

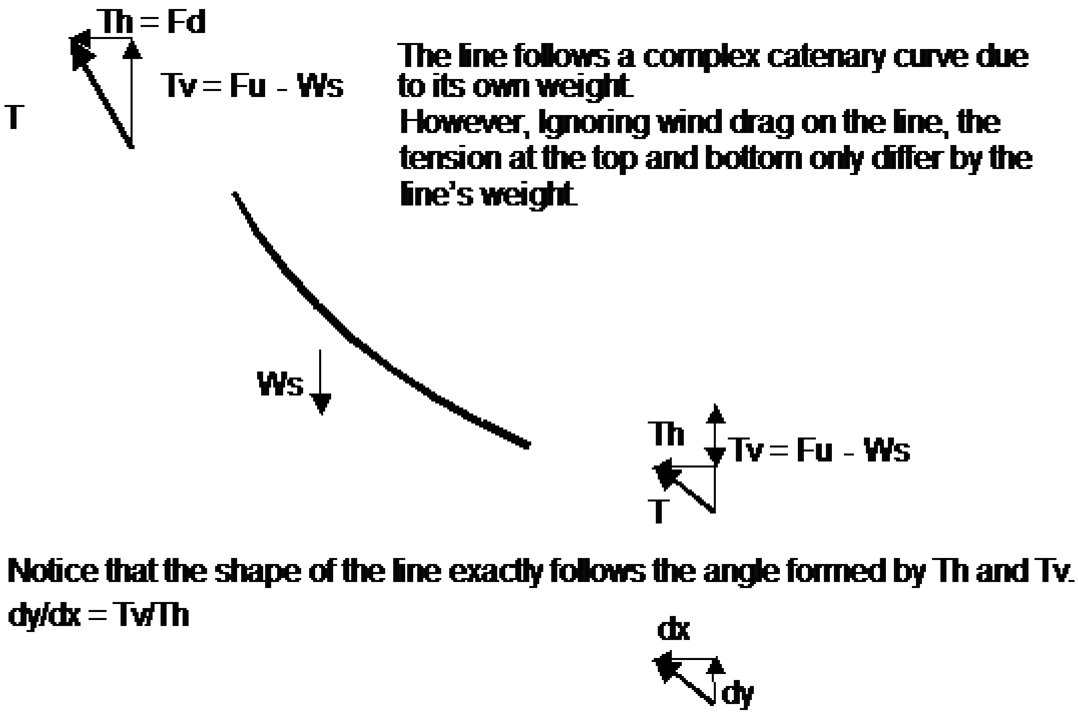
$W_1 = W_b + W_g$ = ��110g + 1450g = 1560 g = 15 N
$W_2 = W_b + W_g$ =�� 300g + 1450g = 1750 g = 17 N
$W_3 = W_b + W_g$ = 1200g + 1450g = 2650 g = 26 N
In order to have a free lift of 500 g = 5 N at the ground:
r_1 = 2.45 ft������������ C=15.4 ft�������� V=46 ft^3 �������� DP=473 psi
r_2 = 2.53 ft ����������� C=15.9 ft�������� V=51 ft^3 �������� DP=523 psi
r_3 = 2.84 ft������������ C=17.8 ft�������� V=72 ft^3 �������� DP=739 psi

For every extra 100 g of payload, we will need an extra 3 ft^3 of helium.� For a std 4 ft cylinder this will require that DP=31 psi

Tension

T = tension in the flight string as a function of flight string length from the balloon.�
Vertical component:� ����� $T_v = F_u$ � W_s
Horizontal component:��� $T_h = F_d$

Height



For a particular balloon, gondola, and 1000 ft of flight string, the altitude achieved will be determined by the ratio of the drag force and the net upward force.� For a particular situation with a required weight to lift and a given wind speed, the only adjustable factor is the Free Lift which requires that we change the inflation radius.

Assumptions and simplifications

Wind is moving uniformly with constant speed and direction and no turbulence.
Temperature is staying relatively constant and heating by sun is negligible.
The density of air remains constant over the entire range of altitude.
The string and gondola experience negligible drag.
The coefficient of drag is 0.5.

Flight Analysis

Using the above parameters, a mathematical model has been created (using Mathcad).� From it the following guidelines have been estimated.

Balloon type 1

Minimum requirements for various Wind Speeds

Given:�� W = 15 N������������ L = 1000 ft����� m = 350 g/1000 ft
with wind speeds:� v = 1, 2, 5,� &10 knots
In order the achieve at least 90% (900 ft) altitude we need the following:

Wind Speed	Desc	Free Lift at ground	Inflation Radius	Diameter	Circumference
1 knot	Calm	350 g	2.43 ft	4.86 ft	15.3 ft
2 knot	Light Air	375 g	2.44 ft	4.88 ft	15.3 ft

5 knots	Light Breeze	1.1 kg	2.72 ft	5.44 ft	17.1 ft
10 knots	Gentle Breeze	10 kg	4.43 ft	8.86 ft	27.8 ft

Maximum Altitudes and String Angles for various Wind Speeds

Given:������ F_u = 500 gm�� (Free Lift on the ground, � r = 2.5 ft)
W = 15 N�������������� L = 1000 ft����� m = 350 g/1000 ft
with wind speeds:� v = 1, 2, 5,� &10 knots
�

Wind Speed	Desc	Maximum Altitude	String Angle from Horiz.
1 knot	Calm	999 ft	85 �
2 knot	Light Air	979 ft	70 �
5 knots	Light Breeze	647 ft	24 �
10 knots	Gentle Breeze	218 ft	6 �

General Guidelines
The balloon must be filled with helium until the balloon plus gondola has a net upward lift that is at least equal to the weight of 1000 ft of string (375 g).

In order to keep the maximum altitude within 10% (i.e. > 900 ft); for every knot of windspeed above 2 knots the balloon should have at least another 4 N (400 g) of net lift.

Increasing the radius by 10% will increase the free lift by about 60% of the total weight.

Appendix A:� Wind Speeds

Knots	Beaufort Number	Name	Effects observed
Under 1	0	Calm	Calm; smoke rises vertically
1-3	1	Light air	Smoke drift indicates wind direction; vanes do not move.
4-6	2	Light breeze	Wind felt on face; leaves rustle; vanes begin to move.
7-10	3	Gentle breeze	Leaves, small twigs in constant motion; light flags extended.
11-16	4	Moderate breeze	Dust, leaves, and loose paper raised up; small branches move.
17-21	5	Fresh breeze	Small trees in leaf begin to sway.
22-27	6	Strong breeze	Larger branches of trees in motion; whistling heard in wires.
28-33	7	Near Gale	Whole trees in motion; resistance felt in walking against wind.
34-40	8	Gale	Twigs and small branches broken off trees; progress generally impeded.

Bowditch, *American Practical Navigator*, U.S. Naval Oceanographic Office, 1966