High-Altitude Balloon Atmospheric Database

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How much gas does it actually take to lift a payload using a latex weather balloon? This question has many answers depending on the mass of your payload, the size and mass of the balloon, and the type of gas being used to lift the balloon. Guessing the amount of fill for the balloon can either waste gas if the balloon doesn't need as much to lift the load or cause negative effects if the balloon is not filled enough, such as hovering in the jet stream pushing a balloon farther than anticipated. Either way, resources are wasted whether it is gas wasted in unnecessary overfilling or time and effort wasted to recover a wayward balloon. Having a database to calculate the necessary fill for a balloon can save time and money. In addition, the data base gives many atmospheric properties with altitude for helping understand balloon data: Standard Atmospheric temperature, pressure, and density profiles, velocity, coefficient of drag, free lift, gravity, lifting force, drag force, speed of sound, thermal conductivity, kinetic temperature, dynamic viscosity, kinematic viscosity, mole volume, mean air particle speed, mean collision frequency, and mean free path.

Nomenclature

A_b	=	Surface area of the balloon (m^2)
A_c	=	Cross sectional area (m^2)
C_D	=	Coefficient of drag
F_D	=	Force due to atmospheric drag
F_{lift}	=	Lifting force of the gaseous fill in the balloon (N, lb_f)
FL	=	Free lift (kg)
g	=	Gravity
h_c	=	Convective heat transfer coefficient
k	=	Thermal conductivity $\left(\frac{J}{m\,s\,K}\right)$
M_a	=	Molar mass of air. (28.9644 g/mol)
M_g	=	Molar mass of gas. Helium: 4.0026 g/mol, Hydrogen gas (H_2): 2.0158 g/mol
m_g	=	Mass of gas (kg). Helium or Hydrogen.
m_{tot}	=	Total mass: Includes payload, balloon, and ballast masses (kg)
n	=	Moles = mass/Molar mass
P	=	Pressure
P_a	=	Atmospheric pressure. (atm, Psi)
P_g	=	Pressure of gas. (atm, Psi)
ρ_a	=	Mass density of air (kg/m^3)
ρ_g	=	Mass density of gas (kg/m^3)
Q	=	Heat
R	=	Gas constant. $8.206 \times 10^{-5}\,\frac{\mathrm{m^3 atm}}{\mathrm{mol\,K}}$
T	=	Temperature
t	=	Time
T_a	=	Temperature of atmosphere. Kelvin (K) and Celsius (°C)
T_g	=	Temperature of gas. Kelvin (K) and Celsius (°C)
V	=	Volume
V_b	=	Volume of balloon (m^3)
v_b	=	Velocity of balloon (m/s)

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I. Introduction

HIGH altitude balloons can be used for a variety of purposes. They have the potential to test satellite sensors in the near space environment. Students can harness the unique environment of traveling through the atmosphere as well as near space to perform experiments to broaden their educational experience. High altitude balloons allow people to discover. For these reasons and many others it should be a priority to know as much as possible about where these balloons are going and how to get them there. Many factors contribute to how high a balloon can go. The atmospheric temperature, pressure, air density, size of balloon, amount of fill, payload mass and many other factors contribute to what altitude a balloon can reach. Some surprising conclusions can be drawn from the use of a database like this as well as its use for atmospheric research. Data relationships can be observed through multiple charts such as temperature, pressure, and air density profiles, effects of altitude on the lifting force, rate of velocity, relationship of free life and ascent velocity, altitude versus time flight paths, calculated coefficient of drag for different balloon sizes with altitude, and many others. This database was created in Microsoft Excel. The balloons used in the database calculations are Tolex Sounding and Pilot Balloons purchased from Kaymont Consolidated Industries. The gas tank specifications are based on Helium and Hydrogen tanks rented from Indiana Oxygen Company. The purpose of this paper is to convey the usefulness of this high-altitude balloon atmospheric database as well as to serve as a user guide to its utilization and different properties.

II. Formulas and Assumptions

The drag force equation in Eq. (1) was derived using Newton's Second Law of motion using the assumption that the balloon's acceleration is zero or the balloon is moving at a constant velocity. This is the drag force on the balloon including the balloon, ballast, and payload mass. The volume of the balloon is assumed to be spherical.

$$F_D = (-m_{tot})g + \left(\frac{gV_b}{R}\right)\left[\left(\frac{P_a M_a}{T_a}\right) - \left(\frac{P_g M_g}{T_g}\right)\right] \tag{1}$$

The velocity of the balloon, Eq. 3, was derived from another equation for the drag force[1], Eq. 2. The assumption is made that the cross sectional area of the balloon is a circle.

$$F_D = \frac{1}{2} C_D \rho_a v_b A_c \tag{2}$$

$$v_b = \sqrt{\frac{2F_d}{C_d \rho_a A_c}} = \sqrt{\frac{2\left((-m_{tot})g + \left(\frac{gV_b}{R}\right)\left[\left(\frac{P_a M_a}{T_a}\right) - \left(\frac{P_g M_g}{T_g}\right)\right]\right)}{C_D \rho_a \pi \left[\left(\frac{3}{4\pi}\right) V_b\right]^{2/3}}} \tag{3}$$

Equation 4 is derived from the drag force equation, Eq. 2.

$$C_D = \frac{2\,F_D}{\rho_a {v_b}^2 A_c} \tag{4}$$

The volume of the balloon, Eq. 5, was derived using the Ideal Gas Law, Eq. 6.

$$V_b = \frac{n_g R T_g}{P} \tag{5}$$

$$PV = nRT \tag{6}$$

Equation 7 shows the conductive heat transfer equation. The assumption that was made in the database was x = radius. This means that we are looking at the heat transfer at the center of the balloon[2]. The radiated heat transfer and the convective heat transfer of the balloon were not looked at in this database.

$$H = \frac{\Delta Q}{\Delta t} = kA_c\frac{\Delta T}{x} \tag{7}$$

The free lift in this database, Eq. 8, is the free lift that only the balloon provides when filled. This does not account for the added payload and ballast mass.

$$FL = (m_a - m_g) = (\rho_{air}V_b - m_g) \tag{8}$$

The lifting force in Eq. 8 is the lifting force of just the balloon, this does not account for the payload and ballast mass.

$$F_{lift} = (m_a - m_g)g = (\rho_{air}V_b - m_g)g \tag{9}$$

The derivations for the equations above used in this high-altitude balloon atmospheric database can be viewed in the Appendix.

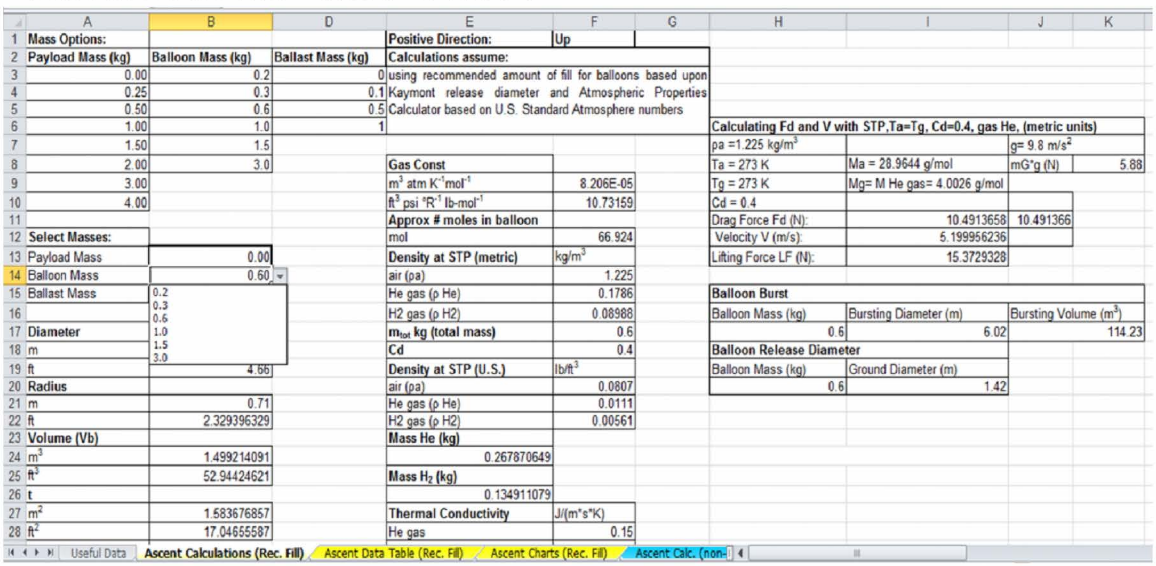
III. High-Altitude Balloon Database Worksheet Descriptions

A. Useful Data

The first worksheet includes useful data from an online atmospheric properties calculator[3] based on the U.S. Standard Atmosphere 1976[4]. The data is taken from 0 km to 40 km in 1 km increments with a 0 m/s air velocity. This useful data includes the speed of sound, dynamic viscosity, kinematic viscosity, mean air particle speed, mean collision frequency, mean free path, and mole volume.

B. Ascent (Recommended Fill)

The Ascent Calculations (Rec. Fill) worksheet shows all the constants and data used in the calculations of the corresponding data table. Drop down lists are also at the users disposal for the payload mass, balloon mass (size of balloon), and ballast mass. The balloon size options are 200 g, 300 g, 600 g, 1000 g, 1500 g, and 3000 g. These will be used to calculate the total mass used in calculations.



	A	B	D	E	F	G	H	I	J	K
1	Mass Options:			Positive Direction:	Up					
2	Payload Mass (kg)	Balloon Mass (kg)	Ballast Mass (kg)	Calculations assume:						
3	0.00	0.2	0	using recommended amount of fill for balloons based upon						
4	0.25	0.3	0.1	Kaymont release diameter and Atmospheric Properties						
5	0.50	0.6	0.5	Calculator based on U.S. Standard Atmosphere numbers						
6	1.00	1.0	1				Calculating Fd and V with STP,Ta=Tg, Cd=0.4, gas He, (metric units)			
7	1.50	1.5					pa =1.225 kg/m³		g= 9.8 m/s²	
8	2.00	3.0		Gas Const			Ta = 273 K	Ma = 28.9644 g/mol	mG*g (N)	5.88
9	3.00			m³ atm K⁻¹mol⁻¹	8.206E-05		Tg = 273 K	Mg= M He gas= 4.0026 g/mol		
10	4.00			ft³ psi °R⁻¹ lb-mol⁻¹	10.73159		Cd = 0.4			
11				Approx # moles in balloon			Drag Force Fd (N):	10.4913658	10.491366	
12	Select Masses:			mol	66.924		Velocity V (m/s):	5.199956236		
13	Payload Mass	0.00		Density at STP (metric)	kg/m³		Lifting Force LF (N):	15.3729328		
14	Balloon Mass	0.60		air (ρa)	1.225					
15	Ballast Mass	0.2 0.3 0.6 1.0 1.5 3.0		He gas (ρ He)	0.1786		Balloon Burst			
16				H2 gas (ρ H2)	0.08988		Balloon Mass (kg)	Bursting Diameter (m)	Bursting Volume (m³)	
17	Diameter			m_{tot} kg (total mass)	0.6		0.6	6.02		114.23
18	m			Cd	0.4		Balloon Release Diameter			
19	ft	4.66		Density at STP (U.S.)	lb/ft³		Balloon Mass (kg)	Ground Diameter (m)		
20	Radius			air (ρa)	0.0807		0.6	1.42		
21	m	0.71		He gas (ρ He)	0.0111					
22	ft	2.329396329		H2 gas (ρ H2)	0.00561					
23	Volume (Vb)			Mass He (kg)						
24	m³	1.499214091		0.267870649						
25	ft³	52.94424621		Mass H₂ (kg)						
26	t			0.134911079						
27	m²	1.583676857		Thermal Conductivity	J/(m*s*K)					
28	ft²	17.04655587		He gas	0.15					

Useful Data | Ascent Calculations (Rec. Fill) | Ascent Data Table (Rec. Fill) | Ascent Charts (Rec. Fill) | Ascent Calc. (non-

Figure 1. Screen shot of the Ascent Calculations Recommended Fill Database Excel worksheet. *This is the second worksheet in the database. There are more to the worksheets than can be seen in the figures.*

The corresponding data table is in the following worksheet in Figure 2, Ascent Data Table (Rec. Fill), in the database. Included in this data table is the altitude in meters and feet, calculated time for a Helium and Hydrogen fill from the velocities, atmospheric temperature[3], temperature of gas from an educated estimated temperature difference, atmospheric pressure in atmospheres and pounds per square inch[3], air density[3], calculated volume of balloon, calculated balloon surface area, calculated balloon cross sectional area, calculated conductive heat transfer, calculated gas density in balloon, calculated velocity for Hydrogen and Helium, calculated drag coefficient from Kaymont initial volume and velocity data[5], calculated free lift, lifting force, and drag force for Hydrogen and Helium.

Time (He) Sec. (s)	Time (H_2) Sec. (s)	Temp atmo. (K)	Temp atmo. (°C)	Temp gas (K)	Temp gas (°C)	ΔT (Ta-Tg) (K, °C)	Pressure (atm)	Pressure (Psi)	ρ of air (kg/m³)	Vb (m³)	Dia. of bal. (m)	Surface Area (m²)	Cross. Sec. Area (m²)	C. S. Area/rad. (m)	Conductive Heat Trans (J/s) He
0	0	288.15	15.00	286.15	13.00	2.0	1.000	14.696	1.225	1.57	1.44	6.54	1.63	2.27	0.68
177	167	281.65	8.50	279.65	6.50	2.0	0.887	13.036	1.112	1.73	1.49	6.97	1.74	2.34	0.70
354	333	275.15	2.00	273.15	0.00	2.0	0.785	11.531	1.007	1.91	1.54	7.45	1.86	2.42	0.73
530	500	268.66	-4.49	266.66	-6.49	2.0	0.692	10.171	0.909	2.12	1.59	7.97	1.99	2.50	0.75
707	667	262.17	-10.98	260.17	-12.98	2.0	0.609	8.944	0.819	2.35	1.65	8.54	2.14	2.59	0.78
884	833	255.68	-17.47	253.68	-19.47	2.0	0.533	7.840	0.736	2.61	1.71	9.17	2.29	2.68	0.81
1061	1000	249.19	-23.96	246.19	-26.96	3.0	0.466	6.850	0.660	2.90	1.77	9.84	2.46	2.78	1.25
1237	1166	242.70	-30.45	238.70	-34.45	4.0	0.406	5.963	0.590	3.23	1.83	10.57	2.64	2.88	1.73
1414	1332	236.22	-36.93	231.22	-41.93	5.0	0.352	5.172	0.526	3.61	1.90	11.38	2.84	2.99	2.24
1590	1498	229.73	-43.42	223.73	-49.42	6.0	0.304	4.469	0.467	4.04	1.98	12.27	3.07	3.10	2.79
1767	1664	223.25	-49.90	216.25	-56.90	7.0	0.262	3.845	0.414	4.54	2.05	13.26	3.32	3.23	3.39
1943	1829	216.77	-56.38	208.77	-64.38	8.0	0.224	3.294	0.365	5.12	2.14	14.36	3.59	3.36	4.03
2119	1994	216.65	-56.50	207.65	-65.50	9.0	0.191	3.250	0.312	5.96	2.25	15.89	3.97	3.53	4.77
2295	2160	216.65	-56.50	206.65	-66.50	10.0	0.164	2.406	0.267	6.94	2.37	17.59	4.40	3.72	5.57
2471	2325	216.65	-56.50	205.65	-67.50	11.0	0.140	2.056	0.228	8.08	2.49	19.47	4.87	3.91	6.45
2646	2489	216.65	-56.50	204.65	-68.50	12.0	0.120	1.758	0.195	9.40	2.62	21.54	5.39	4.11	7.40
2822	2654	216.65	-56.50	204.65	-68.50	12.0	0.102	1.503	0.166	11.00	2.76	23.92	5.98	4.33	7.80
2998	2819	216.65	-56.50	204.65	-68.50	12.0	0.087	1.284	0.142	12.87	2.91	26.56	6.64	4.57	8.22
3174	2983	216.65	-56.50	204.65	-68.50	12.0	0.075	1.098	0.122	15.05	3.06	29.48	7.37	4.81	8.66
3349	3148	216.65	-56.50	204.65	-68.50	12.0	0.064	0.939	0.104	17.61	3.23	32.73	8.18	5.07	9.13
3525	3313	216.65	-56.50	204.65	-68.50	12.0	0.055	0.803	0.089	20.59	3.40	36.33	9.08	5.34	9.62
3701	3478	217.58	-55.57	205.58	-67.57	12.0	0.047	0.686	0.076	24.19	3.59	40.45	10.11	5.64	10.15
3877	3642	218.57	-54.58	206.57	-66.58	12.0	0.040	0.588	0.065	28.40	3.79	45.01	11.25	5.95	10.70
4052	3807	219.57	-53.58	207.57	-65.58	12.0	0.034	0.503	0.055	33.32	3.99	50.07	12.52	6.27	11.29
4228	3972	220.56	-52.59	208.56	-64.59	12.0	0.029	0.431	0.047	39.05	4.21	55.66	13.92	6.61	11.90
4404	4137	221.55	-51.60	209.55	-63.60	12.0	0.025	0.370	0.040	45.74	4.44	61.85	15.46	6.97	12.55
4580	4302	222.54	-50.61	210.54	-62.61	12.0	0.022	0.318	0.034	53.53	4.68	68.69	17.17	7.35	13.22
4755	4466	223.54	-49.61	211.54	-61.61	12.0	0.019	0.273	0.029	62.61	4.93	76.25	19.06	7.74	13.93

Ascent Data Table (Rec. Fill) | Ascent Charts (Rec. Fill) | Ascent Calc. (non-Rec. Fill) | Ascent Data Tab (non-Rec. Fill)

Figure 2. Data Table for Ascent Calculations Recommended Fill. *The differently marked sections represent the troposphere, tropopause, and the stratosphere.*

Associated with this data table are the charts on the next sheet in the database, Ascent Charts (Rec. Fill). The charts included on this worksheet are effects of altitude on lifting force, rate of velocity, relationship between free lift and ascent velocity, and flight path for Helium and Hydrogen. Also included is the increase of the drag coefficient with altitude, temperature, pressure and air density profiles, attainable altitude with increasing payload mass for fixed recommended fill per balloon size, and example rate of increase of velocity with decreasing payload mass (0.2 kg balloon).

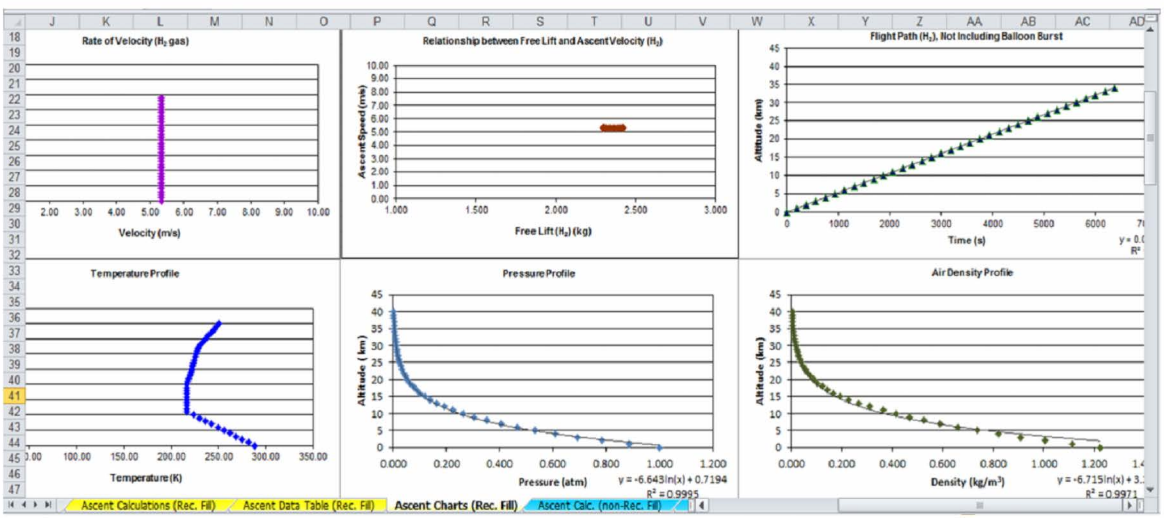


Figure 3. Charts for Ascent Recommended Fill data.

C. Ascent (Non-Recommended Fill)

For a non-recommended fill, the database user has the option of selecting how many tanks of Helium or Hydrogen to put in the balloon through another drop down list. The amount of gas in moles is calculated and viewable for the number of tanks selected using Eq. 6. The tank volume being used in this data base is 291 ft^3 for Helium and 191 ft^3 for Hydrogen gas. The Ascent Calc. (non-Rec. Fill) has the same layout as Ascent Calc. (Rec. Fill) except for the addition of the section in Figure 4.

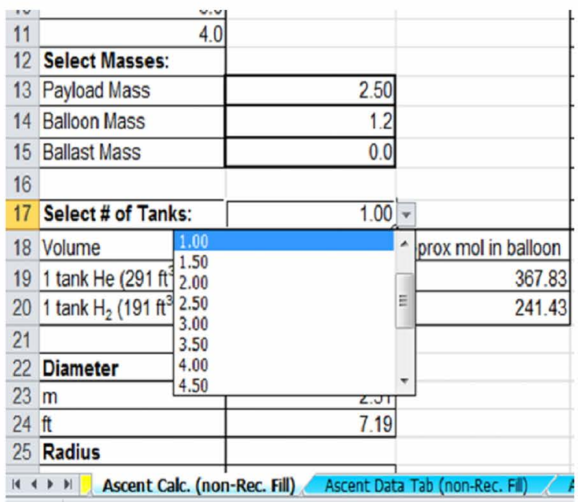


Figure 4. Section view of Ascent Calc. (non-Rec. Fill) worksheet. *The above figure shows the addition to this worksheet of the drop down list for inputting the number of tanks of gas to be used in a balloon fill.*

The Ascent Data Table for the non-recommended fill section has the same properties that were found in the Ascent Data Table Recommended Fill. Included in this data table, like the previous, is the altitude in meters and feet, calculated time for a Helium and Hydrogen fill from the velocities, atmospheric temperature[3], temperature of gas from an educated estimated temperature difference, atmospheric pressure in atmospheres and pounds per square inch[3], air density[3], calculated volume of balloon, calculated balloon surface area, calculated balloon cross sectional area, calculated conductive heat transfer, calculated gas density in balloon, calculated velocity for Hydrogen and Helium, calculated drag coefficient from Kaymont initial volume and velocity data[5], calculated free lift, lifting force, and drag force for Hydrogen and Helium.

There is one curiosity to mention regarding the drag force for this section using Eq. 1. This section uses Eq.1 to calculate the drag force, however if you over fill or under fill a balloon there may or may not be a constant velocity. In this case, the drag force would have to be derived again to account for the balloon acceleration. Changing the drag force in this way would also change the velocity, Eq. 3.

An example chart from the Ascent Non- Recommended Fill worksheet in this section can be viewed in Figure 5.

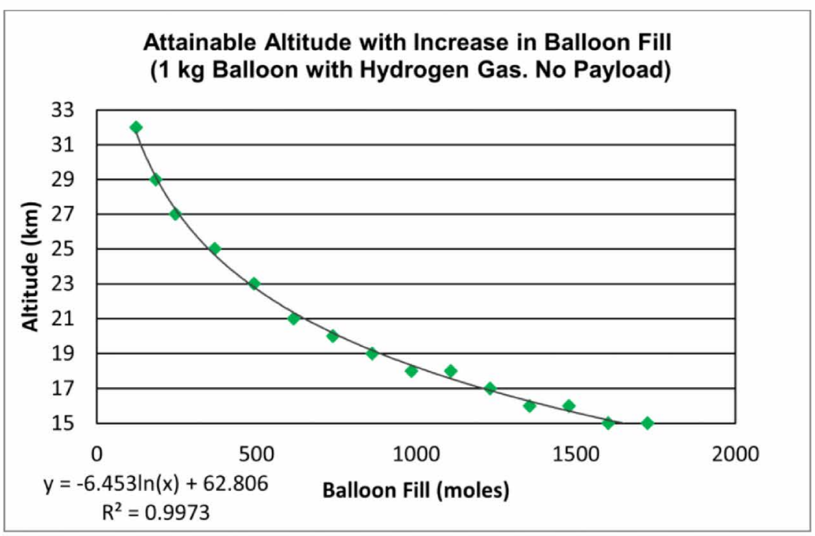


Figure 5. Chart from Ascent Charts (non-Rec. Fill) worksheet. *This chart appears to show that the more fill that goes into a balloon does not guarantee a higher altitude. This is because of the volume limit or "bursting volume" of these balloons. From looking at this database section, more fill does cause an increased ascent rate.*

D. Descent Recommended Fill using a Small Balloon

Using a small balloon in a parachute helps reduce the chaotic behavior of a payload in its descent after balloon release[6]. This section of the database is similar to that in Part B except for the balloon size options. The balloon size options for the small balloon are 10 g, 20 g, 30 g, 100 g, 200 g, 300 g, and 600 g. The calculations for this section use the recommended amount of fill for these balloons. However, if this balloon was going to be used in a parachute Fig. 6, the recommended amount of fill would not be used otherwise the balloon will burst before the larger balloon is released. In practice by Jeff Dailey[3] on Taylor University balloon launches, only a small amount of gas is released in a 100g balloon. This gas expands allowing the balloon to reduce chaos without bursting before the larger balloon is released. The gas in the balloon contracts during decent until there is enough air for the parachute to open up and take over. Figure 7 shows a chart of the balloons volume with altitude from the Descent Rec. Fill Chart worksheet.

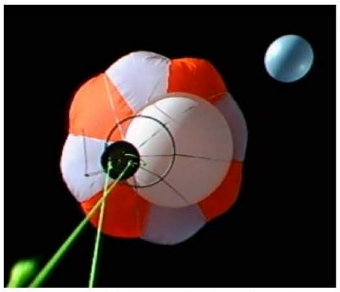


Figure 6. Balloon just after drop. *The smaller auxiliary balloon is seen inside the parachute and the large balloon is in the top right corner and has just been released from our system. (4)*

The data table for this section starts at 40 km and ends at 0 km. The velocity of the balloon is either positive or negative. The velocity is positive if the lifting force is greater than the drag force. This would be, for example, if you chose a large balloon and had a very small payload.

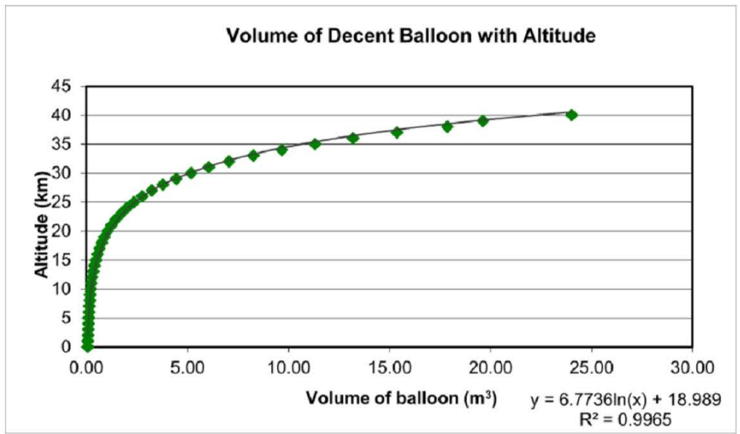


Figure 7. Small balloon volume with altitude.

	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Pressure	ρ of air	Vb	Dia. of bal.	ρHe in balloon	ρH2 in balloon	V	V	Coef. of Drag	Gravity	Free Lift	Free Lift	Lifting Force	Lifting Force	Mag. Drag Force
2	(Psi)	(kg/m³)	(m³)	(m)	(kg/m³)	(kg/m³)	(He)(m/s)	(H_2)(m/s)	Cd	(m/s²)	He (kg)	H_2 (kg)	(He) (N)	(H_2) (N)	(He) (N)
3	0.042	0.004	24.02	Balloon will burst if used w/ rec. fill	0.0006	0.0003	-6.89	-6.84	4.543	9.684	0.082	0.089	0.794	0.861	4.33
4	0.048	0.005	19.62	Balloon will burst if used w/ rec. fill	0.0007	0.0004	-6.89	-6.84	4.487	9.687	0.077	0.084	0.744	0.811	4.34
5	0.055	0.005	17.86	Balloon will burst if used w/ rec. fill	0.0008	0.0004	-6.90	-6.85	4.115	9.690	0.082	0.089	0.794	0.861	4.34
6	0.063	0.006	15.36	Balloon will burst if used w/ rec. fill	0.0009	0.0005	-6.90	-6.85	3.913	9.694	0.082	0.089	0.794	0.861	4.34
7	0.072	0.007	13.19	Balloon will burst if used w/ rec. fill	0.0011	0.0005	-6.90	-6.85	3.719	9.697	0.082	0.089	0.793	0.860	4.34
8	0.083	0.008	11.30	Balloon will burst if used w/ rec. fill	0.0012	0.0006	-6.91	-6.86	3.533	9.700	0.082	0.089	0.793	0.860	4.34
9	0.096	0.010	9.67	Balloon will burst if used w/ rec. fill	0.0014	0.0007	-6.91	-6.86	3.353	9.703	0.082	0.089	0.793	0.860	4.35
10	0.111	0.012	8.26	Balloon will burst if used w/ rec. fill	0.0017	0.0008	-6.91	-6.87	3.181	9.706	0.082	0.089	0.792	0.859	4.35
11	0.129	0.014	7.05	Balloon will burst if used w/ rec. fill	0.0020	0.0010	-6.91	-6.87	3.017	9.709	0.082	0.088	0.792	0.859	4.35
12	0.150	0.016	6.05	Balloon will burst if used w/ rec. fill	0.0023	0.0012	-6.91	-6.87	2.867	9.712	0.082	0.088	0.792	0.859	4.35
13	0.174	0.018	5.18	Balloon will burst if used w/ rec. fill	0.0027	0.0014	-6.92	-6.87	2.725	9.715	0.082	0.088	0.792	0.859	4.35
14	0.202	0.021	4.44	Balloon will burst if used w/ rec. fill	0.0031	0.0016	-6.92	-6.87	2.588	9.718	0.081	0.088	0.792	0.859	4.35
15	0.235	0.025	3.80	Balloon will burst if used w/ rec. fill	0.0037	0.0018	-6.92	-6.88	2.458	9.721	0.081	0.088	0.792	0.859	4.36
16	0.273	0.029	3.26	Balloon will burst if used w/ rec. fill	0.0043	0.0022	-6.92	-6.88	2.334	9.724	0.081	0.088	0.792	0.859	4.36
17	0.318	0.034	2.78	Balloon will burst if used w/ rec. fill	0.0050	0.0025	-6.92	-6.88	2.216	9.727	0.081	0.088	0.792	0.859	4.36
18	0.370	0.040	2.38	Balloon will burst if used w/ rec. fill	0.0059	0.0029	-6.92	-6.88	2.103	9.730	0.081	0.088	0.792	0.859	4.36
19	0.431	0.047	2.03	Balloon will burst if used w/ rec. fill	0.0069	0.0035	-6.92	-6.88	1.995	9.733	0.081	0.088	0.792	0.859	4.36
20	0.503	0.055	1.73	Balloon will burst if used w/ rec. fill	0.0080	0.0040	-6.92	-6.88	1.893	9.736	0.081	0.088	0.792	0.859	4.36
21	0.588	0.065	1.48	Balloon will burst if used w/ rec. fill	0.0094	0.0048	-6.92	-6.89	1.795	9.742	0.081	0.088	0.792	0.860	4.37
22	0.686	0.076	1.26	Balloon will burst if used w/ rec. fill	0.0111	0.0056	-6.92	-6.89	1.702	9.742	0.081	0.088	0.792	0.859	4.37
23	0.803	0.089	1.07	Balloon will burst if used w/ rec. fill	0.0130	0.0066	-6.92	-6.89	1.613	9.745	0.081	0.088	0.792	0.859	4.37
24	0.939	0.104	0.92	Balloon will burst if used w/ rec. fill	0.0152	0.0077	-6.92	-6.89	1.531	9.748	0.081	0.088	0.792	0.860	4.37
25	1.098	0.122	0.78	Balloon will burst if used w/ rec. fill	0.0178	0.0090	-6.92	-6.89	1.454	9.751	0.081	0.088	0.793	0.860	4.37
26	1.284	0.142	0.67	Balloon will burst if used w/ rec. fill	0.0208	0.0105	-6.92	-6.89	1.380	9.754	0.081	0.088	0.793	0.860	4.37
27	1.503	0.166	0.57	Balloon will burst if used w/ rec. fill	0.0244	0.0123	-6.92	-6.89	1.310	9.758	0.081	0.088	0.793	0.861	4.37

Ascent Charts (non-Rec. Fil) | Descent Calculations (SB) | Descent Data Table (SB) | Descent Charts (SB) | Descent C

Figure 8. Data Table for the Decent of a Small Balloon with Recommended fill.

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E. Descent Parachute

The Descent Calculations worksheet for the parachute has significantly less information in it because no gas is involved. There are two options for the mass of the parachute, 100 g and 200 g. The parachute diameter used is 72 inches. The velocity for this section is from Eq. 3 but the drag force is now $m_{tot}g$. This made the assumption that the acceleration is zero; however this does not seem to be the case from Figure 11 from the Decent Charts (Parachute) worksheet. The acceleration would need to be taken into account in the drag equation for a parachute.

Like the data table for the small balloon, the parachute data table goes from 40 km to 0 km. There is significantly less in this data table, Fig. 10, than the previous data tables because of absence of gas being used. Included in this data is the altitude in meters and feet, calculated time from the velocity, atmospheric temperature[3], atmospheric pressure in atmospheres and pounds per square inch[3], air density[3], velocity, calculated free lift, lifting force, and drag force.

	A	B	C	D	E
1	**Mass Options:**			**Positive Direction:**	**Up**
2	**Payload Mass (kg)**	**Parachute mass? (kg)**	**Ballast Mass (kg)**	**Parachute Diameter:**	**72 in or 6 ft**
3	0.0	0.10	0		
4	0.5	0.20	0.1		
5	1.0		0.5		
6	1.5		1		
7	2.0				
8	3.0			**Density at STP (metric)**	kg/m^3
9	4.0			air (pa)	1.225
10				**m_{tot} kg (total mass)**	2.1
11	**Select Masses:**			**Cd**	1.5
12	Payload Mass	2.00		**Density at STP (U.S.)**	lb/ft^3
13	Parachute Mass	0.10		air (pa)	1.293
14	Ballast Mass	0.00			
15					
16	**Diameter Para.**				
17	m	1.83			
18	ft	6.00			
19	**Radius Para.**				
20	m	0.9144			
21	ft	3			
22	**Volume (Vp)**				
23	m^3	1.60127995			
24	ft^3	113.0973355			
25	**C.S. Area Para.**				
26	m^2	1.654762398			
27	ft^2	28.27433388			
28	**Stand.Pressure (P)**				
29	atm	1			

Descent Calculations (SB) | Descent Data Table (SB) | Descent Charts (SB) | Descent Calc. (Parachute) | Desc

Figure 9. Descent Calc. (Parachute) worksheet. *This sheet has information on it for the data table calculations but has significantly less than the previous worksheets because there is no use of gas with a parachute.*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Altitude	Altitude	Time	Temp. Atmo.	Temp. Atmo.	Pressure	Pressure	ρ of air	V Down	Coef. of Drag	Gravity	Drag Force		Troposphere
2	(km)	(ft)	(s)	(K)	(°C)	(atm)	(Psi)	(kg/m^3)	(m/s)	Cd	(m/s^2)	(N)		temp decrease with altitude increase
3	40	131200	0	250.35	-22.80	0.003	0.042	0.004	64.04	1.50	9.684	20.34		Tropopause
4	39	127920	17	247.58	-25.57	0.003	0.048	0.005	59.52	1.50	9.687	20.34		temp constant with altitude increase
5	38	124640	35	244.82	-28.33	0.004	0.055	0.005	55.28	1.50	9.690	20.35		Upper Stratosphere
6	37	121360	54	242.05	-31.10	0.004	0.063	0.006	51.29	1.50	9.694	20.36		temp increase with altitude increase
7	36	118080	75	239.28	-33.87	0.005	0.072	0.007	47.55	1.50	9.697	20.36		Additional comment
8	35	114800	98	236.51	-36.64	0.006	0.083	0.008	44.04	1.50	9.700	20.37		reletivily un-experimented space
9	34	111520	123	233.74	-39.41	0.007	0.096	0.010	40.75	1.50	9.703	20.38		
10	33	108240	149	230.97	-42.18	0.008	0.111	0.012	37.67	1.50	9.706	20.38		
11	32	104960	178	228.49	-44.66	0.009	0.129	0.014	34.81	1.50	9.709	20.39		
12	31	101680	209	227.50	-45.65	0.010	0.150	0.016	32.26	1.50	9.712	20.39		
13	30	98400	242	226.51	-46.64	0.012	0.174	0.018	29.88	1.50	9.715	20.40		
14	29	95120	279	225.52	-47.63	0.014	0.202	0.021	27.67	1.50	9.718	20.41		
15	28	91840	318	224.53	-48.62	0.016	0.235	0.025	25.61	1.50	9.721	20.41		
16	27	88560	360	223.54	-49.61	0.019	0.273	0.029	23.70	1.50	9.724	20.42		
17	26	85280	405	222.54	-50.61	0.022	0.318	0.034	21.92	1.50	9.727	20.43		
18	25	82000	455	221.55	-51.60	0.025	0.370	0.040	20.27	1.50	9.730	20.43		
19	24	78720	508	220.56	-52.59	0.029	0.431	0.047	18.73	1.50	9.733	20.44		
20	23	75440	566	219.57	-53.58	0.034	0.503	0.055	17.31	1.50	9.736	20.45		
21	22	72160	628	218.57	-54.58	0.040	0.588	0.065	15.99	1.50	9.742	20.46		
22	21	68880	696	217.58	-55.57	0.047	0.686	0.076	14.76	1.50	9.742	20.46		
23	20	65600	770	216.65	-56.50	0.055	0.803	0.089	13.62	1.50	9.745	20.46		
24	19	62320	849	216.65	-56.50	0.064	0.939	0.104	12.59	1.50	9.748	20.47		
25	18	59040	935	216.65	-56.50	0.075	1.098	0.122	11.65	1.50	9.751	20.48		
26	17	55760	1028	216.65	-56.50	0.087	1.284	0.142	10.77	1.50	9.754	20.48		
27	16	52480	1128	216.65	-56.50	0.102	1.503	0.166	9.96	1.50	9.758	20.49		
28	15	49200	1237	216.65	-56.50	0.120	1.758	0.195	9.21	1.50	9.761	20.50		
29	14	45920	1354	216.65	-56.50	0.140	2.056	0.228	8.51	1.50	9.764	20.50		
30	13	42640	1481	216.65	-56.50	0.164	2.406	0.267	7.87	1.50	9.767	20.51		

Descent Data Table (SB) | Descent Charts (SB) | Descent Calc. (Parachute) | Descent Data Table (Parachute) | Desce

Figure 10. Descent Data Table (Parachute).

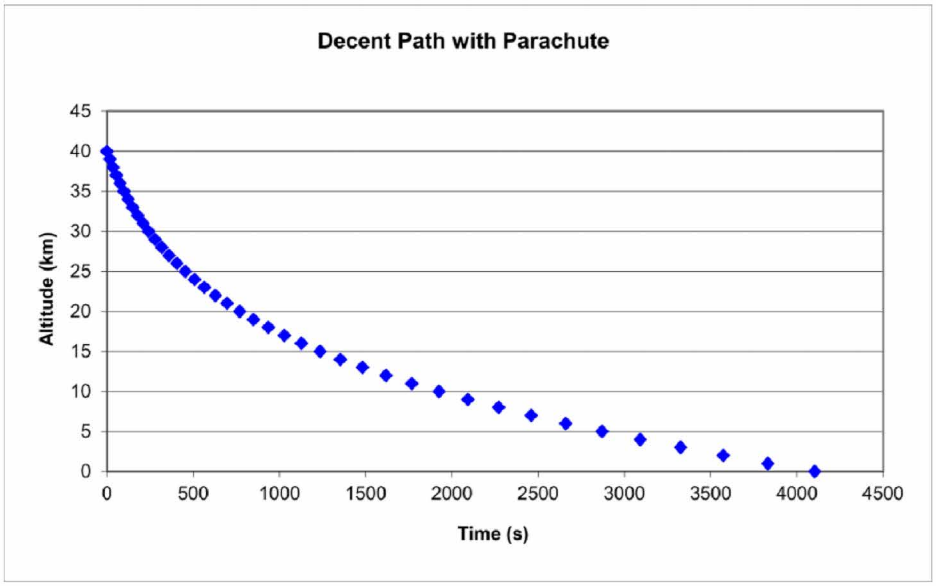

Figure 11. This shows that the velocity is increasing so the acceleration is probably not zero.

F. Real Flight Data

Currently, real flight data is being taken and analyzed at Taylor University. More data needs to be taken to help verify the accuracy and prediction value of this database as well as identify any equation or calculation errors.

IV. Additional Notes and Future Work

While going through the atmospheric balloon database a few items found need to be addressed. An earlier section, III part C, mentioned the possible addition of acceleration to equation 1 and equation 3 for the case of a non-recommended fill. Whether or not this is necessary is yet to be determined. Analysis of real flight data for an over fill and under fill would be able to determine if acceleration is a factor that needs to be taken into account.

Also, the coefficient of drag, Eq. 4, for each balloon and altitude was determined from the initial balloon cross sectional area form the initial volume[5] of the balloon the calculated cross sectional area for each altitude, the air density for each altitude, the rate of ascent[3], and the calculated drag force for that balloon and payload mass[5]. The coefficient of drag analysis for these balloons could be done in greater detail with flight data for more accurate coefficient of drag values.

The free lift and lifting force are currently that of just the balloon not taking the total mass into consideration at the moment. The drag force is the drag force of the balloon or parachute with the total mass. One question is whether it would be more useful to have these forces of just the balloon or have them take into account the inputted payload and ballast masses, or total mass. One future consideration would be to add more detail to this database such as a smaller altitude increment than 1 km, more gas tank size options, more payload mass options, an option for inputting your own temperature, pressure, and air density data and initial conditions. Introducing this database into a webpage or some other means of availability to make it easier to use is another suggestion for the future.

This atmospheric balloon database will be available for beta testing. Any errors, additional comments, changes to equations, or anything to increase the benefit of this database to the high altitude ballooning community would be greatly appreciated.

V. Conclusions

One conclusion that has been drawn from this database that could be further tested was an increase in balloon fill does not guarantee a higher reachable altitude because of a balloon bursting volume but it does give an increased ascent rate, Fig. 5. With this knowledge, a person can perform a faster flight when the need for quick data is important or if one has more time, can plan a flight that reaches a higher altitude but takes a longer amount of time. Accidents can also be avoided. A person unfamiliar with high altitude ballooning might make the assumption that more gas means more altitude, which could end in a much lower reached altitude than needed, wasted materials, and an inevitable re-flight. Conclusions such as this can be useful when planning a high altitude balloon flight.

Knowing where high altitude balloons are going or how to get them there increase the reliability and value in using high-altitude ballooning for testing, research, and education. The purpose of this high altitude balloon database was to create something for everyone in this community to use and make high altitude balloons a more accurate, cost effective, and convenient way to discover.

Appendix

A. Drag Force Derivation

The assumption was made that the balloon acceleration is equal to zero.

$$\sum F_{tot} = F_{lift} - F_g - F_D = ma = 0$$

Solve for F_D,

$$F_d = F_{lift} - F_g$$

Insert lifting force from Eq. 9,

$$F_D = (m_a - m_g)g - m_{tot}g$$

Solve for mass using Eq. 6,

$$PV = nRT = \frac{m}{M}RT\ ; n = \frac{m}{M}$$

$$m = \frac{PVM}{RT} = V\rho$$

Insert above solved equation in for mass of atmosphere and mass of gas,

$$F_D = g\left(\frac{P_a V_b M_a}{RT_a} - \frac{P_g V_b M_g}{RT_g}\right) - m_{tot}g$$

Simplify,

$$F_D = (-m_{tot})g + \left(\frac{gV_b}{R}\right)\left[\frac{P_a M_a}{T_a} - \frac{P_g M_g}{T_g}\right]$$

B. Velocity Derivation

The assumption was made that the balloon has a circular cross sectional area and a spherical volume.

$$F_D = \frac{1}{2}C_D \rho_a v_b A_c$$

Solve for v_b,

$$v_b = \sqrt{\frac{2F_D}{C_D \rho_a A_c}}$$

Solve for cross sectional area using volume,

$$A_c = \pi\left[\left(\frac{3}{4\pi}\right)\left(\frac{4}{3}\pi r^3\right)\right]^{2/3} = \pi\left[\left(\frac{3}{4\pi}\right)V_b\right]^{2/3} = \pi r^2$$

Substitute F_D and A_c into solved equation for v_b,

$$v_b = \sqrt{\frac{2\left(g\left(\frac{V_b M_a P}{RT_a} - \frac{V_b M_g P}{RT_g}\right) - m_{tot}g\right)}{C_D \rho_a \pi \left[\left(\frac{3}{4\pi}\right) V_b\right]^{2/3}}}$$

C. Volume of Balloon Derivation

$$PV = nRT$$

Solve for volume of balloon using temperature of gas and moles of gas.

$$V_b = \frac{n_g R T_g}{P_g}$$

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Note for reference 5: Data used in paper and database was accessed 6/9/2011 when website was still www.kaymont.com. More detailed spec sheets were available online for Sounding and Pilot balloons when the website was originally accessed. Now for more detailed spec sheets, they need to be requested from Kaymont Consolidated Industries.