CONTRIBUTION TO STATICS AND DYNAMICS OF A HOT-AIR BALLOON

Written By

Pavel Hora, 1988

Translation by

Lea Kiel, 2021

Annotated by

Koh Murai, 2025

<u>Annotator's Notes</u>

This compilation of alternate ways to view hot air balloon operations was written by my friend, Pavel Hora, some years ago and given to me during a visit to his home and local balloon club operations (Ballonsportgruppe Stuttgart e.V. - The Stuttgart Balloon Club) https://ballonsportgruppe-stuttgart.de/ , in 1995.

My annotations appear in this work inside brackets and in italics *[annotations]* to be readily differentiated from Pavel's original text. Most are to provide clearer understanding for an audience not used to metric units of measure and translations of German language. There are also some phrase or word equivalents where the direct translation and the normal phrases used in English may be a bit confusing to the reader, so I have attempted to supply the common English for those situations.

The reader should note, if they are not used to reading German technical text, that the use of a comma within a number is the equivalent of the decimal point. As an example; 15,27 = 15.27

K. Murai

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Preface

The hot air balloon is the oldest manned aircraft. It was invented by the Montgolfiere brothers, but the operating principle remained unknown to them. At that time, they did not understand that the load-bearing capacity of the balloon is due to the thermal expansion of the air. Nevertheless, several accident-free flights were made at that time, which proves the unique good nature of this aircraft. We still feel this good-naturedness today, which sometimes tempts us to handle the balloon a little carelessly, i.e. more by instinct than by rational considerations.

During my career as a hobby pilot, I was confronted with some situations that could not be handled by instinct, so I tried to calculate the standard situations of a hot-air balloon in order to better understand the special situations. The basics can be found in every thermodynamics book. The calculations are not overly complicated if you don't include all the influences at once. With the calculations I wanted to show the regularities and capture the typical driving conditions in numbers.

Until now, a nomogram from the manual was used to determine the load-bearing capacity. As explained in the following text, this nomogram can easily be misunderstood, resulting in considerably overloading the balloon.

The calculation laid out here attempts to take better account of the driving conditions and to expand the information on other important physical relationships. For better comprehensibility, each calculation is explained by one or more practical examples.

Correlations between the variable values determine driving behavior. Although we are dealing with an Aerostat, it is exposed to dynamic forces due to its own movement and movement of the air masses externally and internally.

In a hot-air balloon we can generate counterforces by added heat and by exploiting its physical consequences. The relevant variables are:

- external temperature *[ambient temperature outside the envelope]*
- internal temperature *[envelope internal temperature)*
- altitude [*altitude, MSL]*
- wind force *[wind speed]*
- balloon size *[envelope volume]*
- heat added *[net heat added by burning fuel]*
- heat loss [*heat loss through the envelope and openings]*
- burner output
- occupant weight
- rate of climb
- velocity of fall [*descent rate]*

The calculation shows the interdependence of these variables to each other, whereby only some typical states are involved to show the order of magnitude of this dependency. This is not a collection of tables that lists all possible values for every other variable. So, if you want to record a landing of a hot-air balloon in 6000 m altitude, please calculate it yourself.
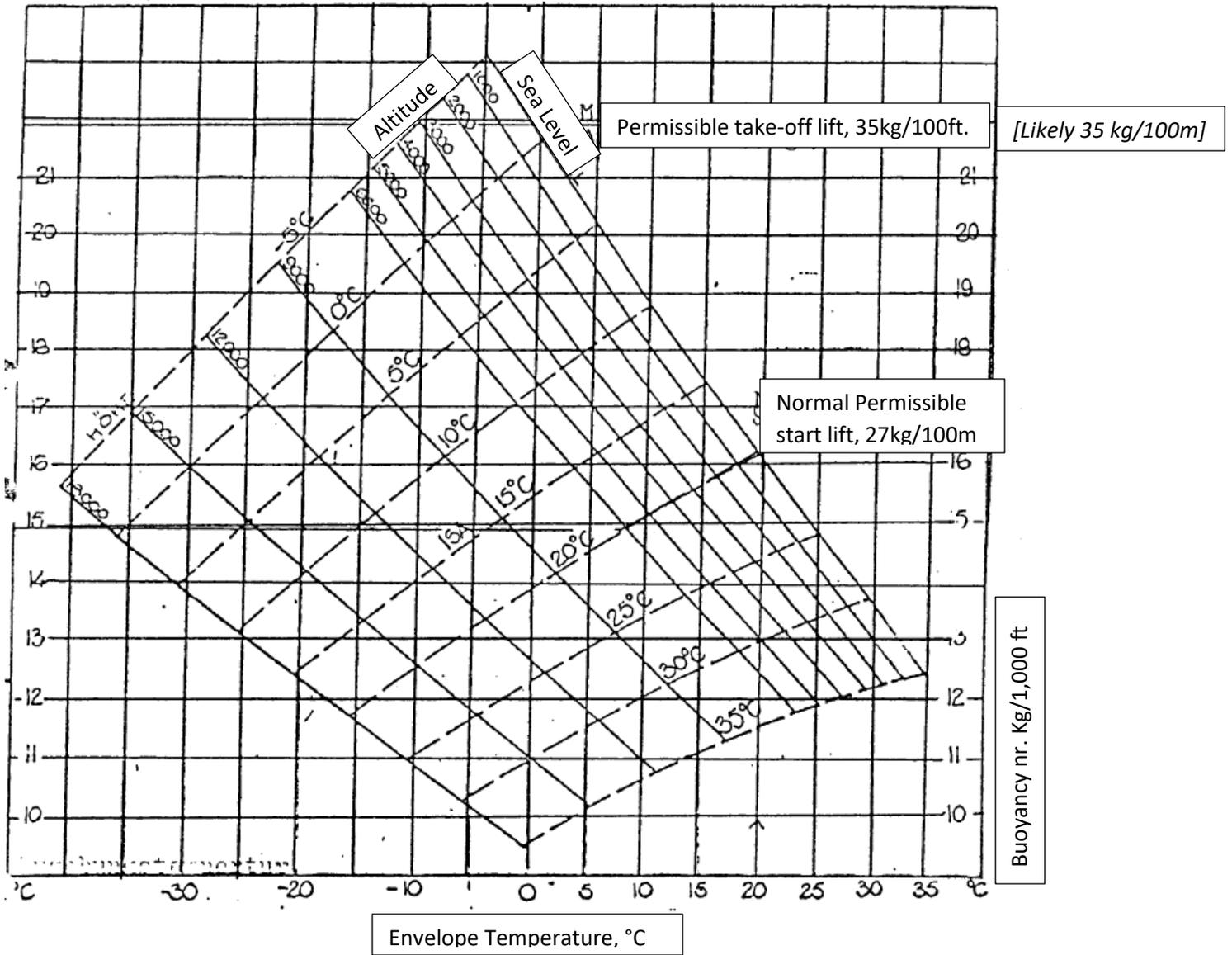
I hope that these tables and diagrams are not considered as dead matter by hot air pilots. On the contrary, I expect them to be brought to life by the pilots' experience.

Pavel Hora

September 1988

Chapter 1: Load capacity of hot air

Diagram 1

1.1 <u>Load capacity diagram in the manual</u>
The diagram shows the dependency of the specific load capacity in kg/1000 ft^3 on the external temperature in °C at an internal balloon temperature of 100 °C.
Unfortunately, however, it can easily be misinterpreted for 2 reasons:
1. The external temperatures listed on the dotted lines are only valid for 0 m altitude.
2. Even the "correctly" determined load capacity is not the load with which one should reasonably start.

<u>Regarding 1.</u>
The dashed lines represent the decrease of the load-bearing capacity in relation to the altitude, considering the temperature decrease of 6.5 °C/1000 m altitude (3280 ft). The temperatures along these lines are only valid for 0 m altitude.
Here are some examples:
a)   Altitude: 0 ft
        External temperature: 20 ° C
        Spec. load capacity: slightly over 16;
        ---   Later, the balloon travels at an altitude of 6000 ft, specific load capacity 15.
b)   Altitude: 6000 ft
        External temperature: 20 ° C
        Spec. load capacity: 12.5 ! not 15 at the 20° line,
        but 12.5 on the line between 30 ° - 35 °
        ---   Then the balloon will later go to 9000 ft altitude, spec. load capacity 12.
Note: You go down approximately at the 32 ° line and not at the 20 ° line, because you actually measured the 20 °C at the altitude of 5000 ft. This also means that if you start in these conditions, the temperature would be about 32° when you descend to 0 ft.
An incorrect reading of the diagram would lead to an overload in a 3000 m^3 balloon in this case by almost 100 kg, which would result in an approx. 16 °C higher internal temperature.

<u>Regarding 2.</u>
The diagram was often understood in such a way that the load carrying capacity determined here represents the maximum permissible load at which one can just about start. It does not consider the fact that even the simple interception of the balloon has a higher load-bearing capacity than the purely statistically calculated requirement and, in the case of gusts, additional load-bearing capacity is necessary to keep the balloon under control.
These correlations are explained in the following text.
Here it is shown that one needs about 8 °C reserve to the mere statistical situation to counteract 3 m down draft.

There is another shortcoming of this diagram:
The pilot needs to calculate his payload from the data read off, which is usually perceived as too annoying and laborious.
The following text contains diagrams that enable the pilot to be informed quickly, easily, and in a way that is meaningful from a technical driving point of view.
Diagrams 3, 4 and 5 in particular are of valuable help for the load capacity.
The first step is to calculate the specific load-bearing capacity of the hot air as a function of the external temperature and altitude - at a constant internal temperature in the balloon.

Diagram 1

Total load capacity: envelope temperature 100 °C

Envelope Temperature, °C

Total lift for balloon size. (kg)

Buoyancy, Kg/1000 ft.	AX4 31	AX5 42	AX6 56	AX7 65	AX7 77	AX8 84	AX8 90	AX8 105	AX9 140	[Balloon vol. M ft³]
10	140	191	256	296	350	381	409	477	656	
11	155	210	281	325	385	420	450	525	700	
12	169	229	306	355	420	458	491	573	764	
13	183	248	331	384	455	496	532	621	828	
14	197	267	356	414	490	534	573	669	891	
15	211	286	381	443	525	572	614	717	955	
16	225	305	406	473	560	610	655	764	1019	
17	239	324	431	502	595	649	696	812	1083	
18	253	343	456	532	630	687	737	860	1146	
19	267	362	481	561	665	725	778	908	1210	
20	281	381	506	591	700	763	819	956	1274	
21	295	400	531	620	735	801	860	1004	1338	

<u>1.2 Calculation of the specific weight of the air and the specific load capacity as a factor of the external temperature and altitude</u>

See also   Table 1 .... for the internal balloon temperature of 100 °C

                 Table 2 .... for the internal balloon temperature of 95 °C

                 Diagram 2

In both tables it is calculated the specific gravity of external air Y_A, air in the envelope Y_i, and the specific carrying capacity of air in balloon t for the external temperature of 0 ° to 40 ° and altitudes of 0 m to 5000 m above sea level. The specific gravity of the air depends on the air pressure and temperature. However, the specific load capacity depends on 3 factors: -- air pressure, external and internal temperature.

The load capacity calculation was calculated for 2 fixed internal temperatures of 95 ° and 100 °.

According to the table:	at internal temperature	100 °.	
	external temperature	0 °	
	Altitude	0 m	= 0.347 kg/m³
	Internal temperature	100 °	
	external temperature	40 °	
	Altitude	5000 m	= 0,097 kg/m³

The correlations are also shown graphically in diagram 1.

<u>First example:</u>

The balloon should start with a capacity of 3000 m³ at an altitude of 1000 m. The external temperature is 17 °C. What load can be carried in order not to exceed the operating temperature of 95 °C at the altitude of 2000 m?

Solution:

The temperature-drop when climbing 1000 m is usually 7 °C.

The external temperature in 2000 m is therefore 10 °C.

The specific loading capacity for 95 °C internal temperature is 0.226 kg/m³ according to Table 2.

Load capacity of the balloon:	0.226 x 3000 m	= 678 kg
	<u>minus net weight</u>	<u>- 350 kg</u>
	max. weight of the crew:	328 kg

Therefor the balloon can still start with 4 people.

<u>Second example:</u>

The balloon with a capacity of 2200 m³ should start at an altitude of 500 m with an external temperature of 30 °C. An inversion at an altitude of 1000 m is predicted, up to this altitude no significant drop in temperature is to be expected. How many people can you take with you in order not to exceed the internal temperature of 95°C at an altitude of 1000 m?

Solution:

Load capacity at 1000 m altitude at 30 °C = 0.182 kg/m³

Load capacity of the balloon:	0.182 x 2200 m³	= 400.4 kg
	<u>minus net weight</u>	<u>-290.0 kg</u>
	max. weight of the crew:	110,4 kg

The balloon can be occupied by only one person of average weight. This also provides a good reserve. Loading 2 people of only 70 kg each would result in a 30 kg excess of the advisable load.

Table 1

Specific weight of the external and internal air
and specific load capacity of the hot air in a hot air balloon (kg/m^3)

Temperature in balloon: 100 °C

External temperature	Altitude (m)																				
	0			500			1000			2000			3000			4000			5000		
	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t
0 °C	1,293	0,946	0,347	1,218	0,891	0,327	1,147	0,839	0,308	1,014	0,742	0,272	0,895	0,655	0,24	0,786	0,575	0,211	0,69	0,50	0,19
10 °C	1,247	"	0,301	1,175	"	0,284	1,106	"	0,267	0,978	"	0,236	0,863	"	0,208	0,758	"	0,183	0,66	"	0,16
20 °C	1,205	"	0,259	1,135	"	0,244	1,069	"	0,230	0,945	"	0,203	0,834	"	0,179	0,733	"	0,158	0,64	"	0,14
30 °C	1,165	"	0,219	1,098	"	0,207	1,033	"	0,194	0,914	"	0,172	0,806	"	0,151	0,708	"	0,133	0,62	"	0,11
40 °C	1,128	"	0,182	1,063	"	0,172	1,000	"	0,162	0,885	"	0,143	0,781	"	0,126	0,686	"	0,111	0,6	"	0,097

[*specific gravity of external air, Ya.   Specific gravity of internal air, Yi*

Table 2

Specific weight of the external and internal air
and specific load capacity of the hot air in a hot air balloon (kg/m^3)

Temperature in balloon: 95 °C

External temperature	Altitude (m)																				
	0			500			1000			2000			3000			4000			5000		
	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t	Y_A	Yi	t
0 °C	1,293	0,959	0,334	1,218	0,904	0,314	1,147	0,851	0,296	1,014	0,752	0,261	0,895	0,664	0,231	0,786	0,583	0,203	0,69	0,51	0,18
10 °C	1,247	"	0,288	1,175	"	0,271	1,106	"	0,255	0,978	"	0,226	0,863	"	0,199	0,758	"	0,175	0,665	"	0,154
20 °C	1,205	"	0,246	1,135	"	0,231	1,069	"	0,218	0,945	"	0,193	0,834	"	0,17	0,733	"	0,149	0,642	"	0,131
30 °C	1,165	"	0,205	1,098	"	0,194	1,033	"	0,182	0,914	"	0,161	0,806	"	0,142	0,708	"	0,125	0,62	"	0,11
40 °C	1,128	"	0,168	1,063	"	0,156	1,00	"	0,149	0,885	"	0,132	0,781	"	0,117	0,686	"	0,102	0,6	"	0,09

Diagram 2

Specific load capacity of 95 °C hot internal air as a factor of external temperature (see Table 2)

Course of the load-bearing capacity with altitude, taking into account the temperature reduction by 0.65 °C/ 100 m altitude

Specific Load-Bearing Capacity [kg/m³]

Envelope Temperature – [°C]

Altitude, m
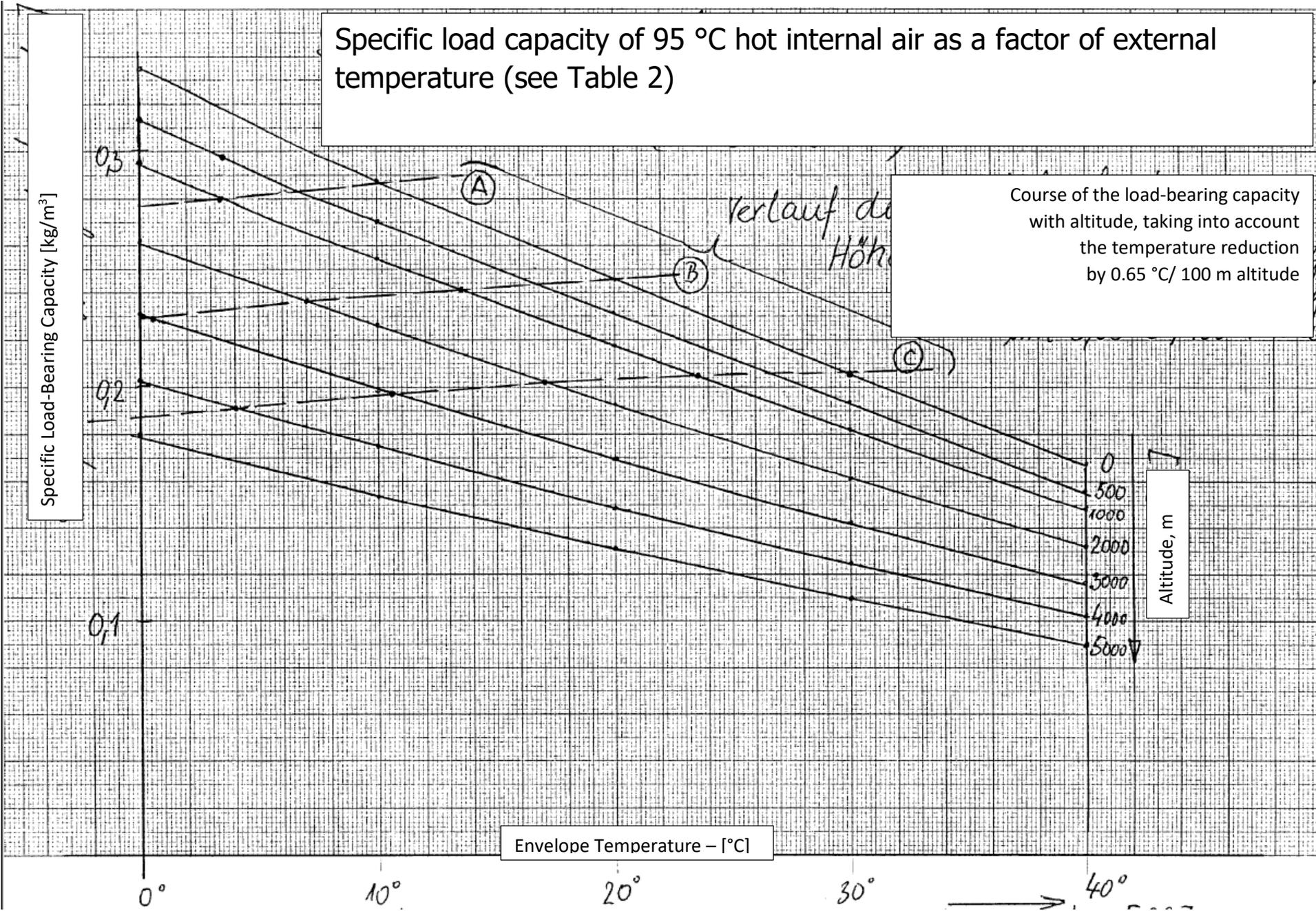
Chapter 2: Expansion of hot air at different external temperatures and an internal temperature of 100 °C

Sketch 2

External temperature °C	Expansion
0	36,6
10	31,8
20	27,3
30	23,1
40	19,0

The expansion of the hot air is the basis of our load-bearing capacity:

$$V\ (\%) = \frac{T2}{T1} - 1$$

In regards of filling the balloon there are other interesting consequences, which are shown in the sketches on the following pages.
We see that only about 25 - 30 % of the content can be filled by turning on the burner. When filling the balloon, it is therefore absolutely necessary to fill 70 - 75 % of the balloon content with cold air - i.e., with the blower - before starting the final heating.
Here the ratio between the power of the blower and the balloon size is important. With a 5 HP blower, a 2200 m³ balloon can usually be filled almost completely with cold air, but a 3000 m³ balloon is only about 1/3 full. The heavy envelope presses against the incoming air and prevents a higher filling level. We can counteract this circumstance by moderate heating, lifting the envelope a little and filling it further with the blower. As shown in the sketch, heating 1/3 of the content to 100 °C already provides the load capacity of 325 kg at a filling level of 1300 m³, which in practice means the set-up of a not even half-filled envelope.

So once again: a correct filling has 3 and not 2 phases:
1. cold blowing
2. change between moderate heating and blowing until about 75 % is reached
3. heat up and set up

Since we followed this rule consistently, there were no difficulties with the burning of envelopes during the filling process.

Conditions during filling of a hot-air balloon
The right approach

buoyancy 0

Phase 1: Fan

$V = 1000 m^3$
$t = 20°C$

Buoyancy about 125 kg

Phase 2:

$V = 1100 m^3$
$t = 50°C$

buoyancy about 150 kg

Phase 3: Fan

$V > 1100 m^3$
$t = 50°C$

buoyancy is about 125 kg

Phase 4: Burner Ful when
balloon filled about 3/4

V mind. $2400 m^3$

Side View   Cross Section View
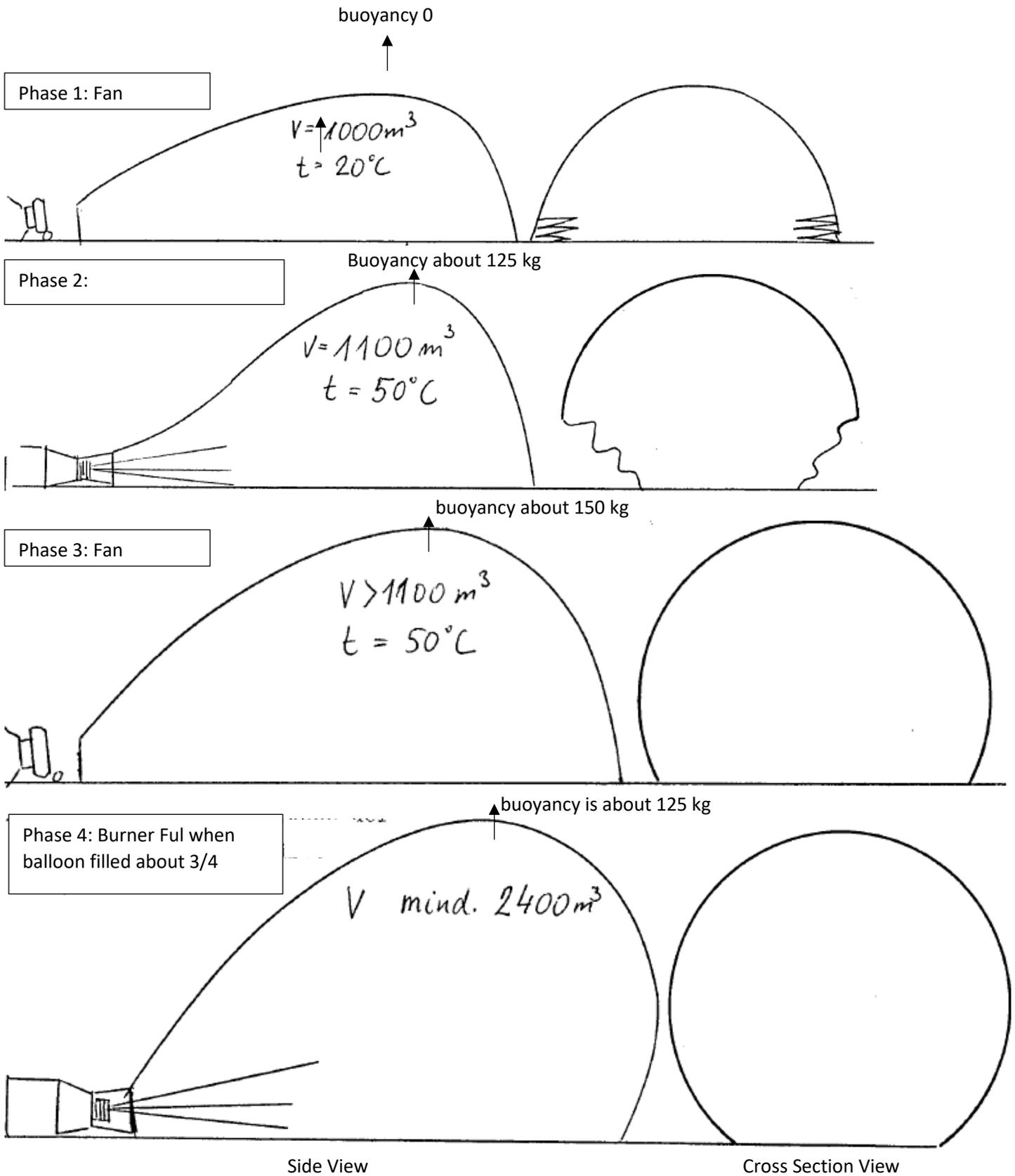
Chapter 3: Relevant weights when operating a hot air balloon

- Table 3 & 4

Table 3 shows the weights of the components, the resulting empty weight of the balloon, and the weights of its crew of 2, 3 and 4 people.

Table 4 summarizes the weights as a function of the internal temperature. Based on the average empty weight of the balloon, the following parameters are listed for the interior temperatures of 95 °C and 100 °C:

    2.1   Total weight of the balloon with the crew at the internal temperatures of 95 °C and 100 °C (excluding the dead weight of hot air in the balloon)
    2.2   Max. possible weight of the crew
    2.3   Weight of the basket with the crew
    2.4   Weight of the envelope, including hot air contained therein
    2.5   Ratio between the weight of the envelope referred to in point 2.4 and the weight of the basket referred to in point 2.3.

All these parameters are calculated as a function of the external temperature at 500 m altitude.

The meaning of the payload according to point 2.2 does not need to be explained separately here. On the other hand, not everyone is sufficiently aware of the importance of the ratio of the weights of basket to envelope according to item 2.5. This ratio plays an important role during landing, as described in chapter 10.

Table 3

Relevant weights of the hot air balloon and its components (average values)

Component [Envelope Volume]	2200 m³ [Weight] (kg)	2550 m³ [Weight] (kg)	3000 m³ [Weight] (kg)
Envelope	85	100	120
basket	40	50	60
double burner	23	23	23
4 bottles à 32 kg	128	128	128
tow rope	5	5	10
instruments	5	5	5
Other	4	4	4
Empty weight of the 4 bottles	290	315	350
With 2 people à 80 kg	450	475	510
With 3 people à 80 kg	530	555	590
With 4 people à 80 kg	610	635	670

Weights of the hot air balloon at 500 m altitude and 1013 hPa [*atmospheric/barometric pressure*]

Table 4

[Envelope] Size			2200 m³		2550 m³		3000 m³	
Tare weight of the balloon with 4 full A1 bottles [Kg]			290		315		350	
Temp. °C	Extern.	Intern.	95°	100°	95°	100°	95°	100°
Total weight of the balloon (kg) without envelope	0°		691	719	801	834	942	981
	10°		596	625	691	724	813	852
	20°		508	537	589	622	693	732
	30°		427	455	495	528	582	621
Crew weight (kg)	0°		401	429	486	519	592	631
	10°		306	335	376	409	463	502
	20°		218	245	274	307	343	382
	30°		137	165	179	213	232	271
Weight of the basket (...) Crew (kg)	0°		606	634	701	734	817	856
	10°		511	540	591	624	688	727
	20°		423	452	489	522	568	607
	30°		342	370	394	428	457	496
Weight of the envelope including hot air (kg)			2074	2045	2405	2372	2837	2798
Ratio weight envelope / weight basket	0° [C]		3,42	3,22	3,43	3,23	3,47	3,27
	10° [C]		4,05	3,79	4,06	3,80	4,12	3,85
	20° [C]		4,90	4,52	4,91	4,54	4,99	4,61
	30° [C]		6,06	5,53	6,10	5,54	6,20	5,64

Chapter 4: Relationship between external and internal temperature at the specific load capacity

Table 5 & 6
Diagrams 3, 4 & 5

4.1 Hot air balloon crew and interior temperature
Based on the weights from Table 3 I calculated the internal temperature in the balloon at different sizes, altitude, and external temperatures. The results are shown in Table 5 and in Diagrams 3, 4 and 5.
Inadmissible starting conditions are shaded in Table 5.
Diagrams 3, 4 and 5 provide much more practical information about the loading of hot air balloons than the loading diagram in the manual, whose weak points we already identified.
What is apparent from these diagrams?
Basically, the dependence of the internal temperature (y-axis) on the external temperature (x-axis) is laid out here for 2 crew variants and 3 altitudes.

Here is an example:
- External temperature 20 °C
- Balloon 3000 m   results in an internal temperature of 92.5 °C
- altitude 500 m
- Crew with 4 people

- the balloon should rise to 1000 m   results in an internal temperature of 93.5 °C
- Temperature 17 °C

This diagram also shows the temperature difference to the max. temperature of 100 °C, which is necessary to compensate the vertical gusts. This grid starts at about 99 °C for a gust of 1 m/s and ends at about 52.5 °C for a gust of 7 m/s for a 3000 m^3 balloon.
This means that a gust of 7 m/s can only be handled at an internal temperature of 52.5 °C - without overheating of the balloon to over 100 °C.

In practice, however, such gusts should be avoided with good weather advice. When driving in the mountains, where even stronger down winds are a regular occurrence, these pose a great potential hazard.
When preparing for a trip under normal conditions, it is sufficient to assume that no gust stronger than 3 m/s will be encountered. To compensate this, we need about 8 ° (C) for the increase of the internal temperature.

For loading the hot air balloon, I took this value as a guideline. This is therefore the intersection of the temperature lines with the line of the 3 m/s gust and decisive for loading the balloon. The responsible external temperature is the relevant temperature at which one can still start with the respective crew.

A rule of thumb in preparation of the next chapter:
Increasing the internal temperature by 1 °C results in the following increases in load capacity
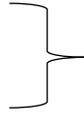- at 3000 m^3 ≈ 7 kg
- at 2550 m^3 ≈ 6 kg
- at 2200 m^3 ≈ 5 kg
Here are a few examples:

First example:
- Start at 500 m altitude

- Balloon 2200 m^3 Crew?
- External temperature 24 °C   Crew?
- max. driving altitude 1000 m
- Temperature there 21 °C

When occupied by 3 persons, the interior temperature would be 105 °C. Therefore, you will decide for only 2 people, meaning 80 kg less;
80 : 5 = 16 °C; starting temperature 89 °C;
Internal temperature at 1000 m altitude: 107 °C - 16 °C = 91 °C

Second example:
- Start at 1000 m altitude
- Balloon 2550 m^3
- external temperature 18 °C   Crew?
- max. driving altitude 2000 m
- Temperature there 12 °C
- gusts of 5 m/s possible

Crew of 4 people leads in 1000 m altitude to an internal temperature of 106 °C, in 2000 m altitude to an internal temperature of 110 °C.
With 3 people, the internal temperature is 92.5 °C at 1000 m altitude and 95 °C at 2000 m altitude.
For a 5 m/s gust you need 14 °C reserve, so you can only start with 2 people.
This results in a reduction of the internal temperature of 80 : 6 = 13.3 °C; therefore, the starting temperature is 79 °C.
Temperature at 2000 m altitude is about 82 °C.

Third Example:
- Crew 2 people
- Alpine trip up to 2000 m altitude   Which gust can be balanced?
- Balloon 3000 m^3
- External temperature in 2000 m = 20 °C

If the crew consisted of 3 people, the internal temperature would be 97 °C.
80 : 7 = 11,5 °C less, that means: 97 °C - 11,5 °C = 85,5 °C.
A gust of
        - 4 m/s with an internal temperature of 100 °C, or
        - 5 m/s with an internal temperature of 108 °C
can be compensated.

Table 5

Internal temperature in the balloon depending on the crew and external temperature (°C)

Pressure 1013 hPa, weight per person 80 kg

External Temperature(°C) / Altitude	Balloon of 2200 m³ Crew 3 People			Crew 4 People			Balloon of 2550 m³ Crew 3 People			Crew 4 People			Balloon of 3000 m³ Crew 3 People			Crew 4 People		
	500 m	1000 m	2000 m	500 m	1000 m	2000 m	500 m	1000 m	2000 m	500 m	1000 m	2000 m	500 m	1000 m	2000 m	500 m	1000 m	2000 m
0	67	72,5	85	80,5	87	103	59	64	74,5	70	76	89	52,5	56,5	66	61	66	77
5	75	80,5	94	89	96	112	67	71,5	83	78	84	98	60	64	73,5	69	74	85,5
10	83	89	102,5	97,5	104,5	122	74	79	91	86	92	107	67	71	81	76,5	81,5	94
15	91	97	111,5	106	113,5	132	82	87	99	94	100,5	116	74	78,5	89	84	89,5	102
20	99	105	120	115	122,5	142	89	95	108	102	109	125	81,5	86	97	92	97,5	110
25	107	113,5	129	123,5	132	152	97	103	116	110,5	117,5	134	89	94	105	99,5	105,5	119
30	115	122	138,5	132	141	162	105	111	125	119	126	143,5	96	101	113	107,5	113,5	128

Diagram 3

Temperature in the balloon in relation to the external temperature and the crew

Balloon: Mickey Mouse

Content: 3000 m³
W. No. of envelope: 007
Weights:
Basket total: 115 kg
Envelope: 110 kg

Empty weight without bottles: 225 kg
Empty weight with 4 bottles: 358 kg
Total weight
    With 2 people: 518 kg
    With 3 people: 598 kg
    With 4 people: 678 kg
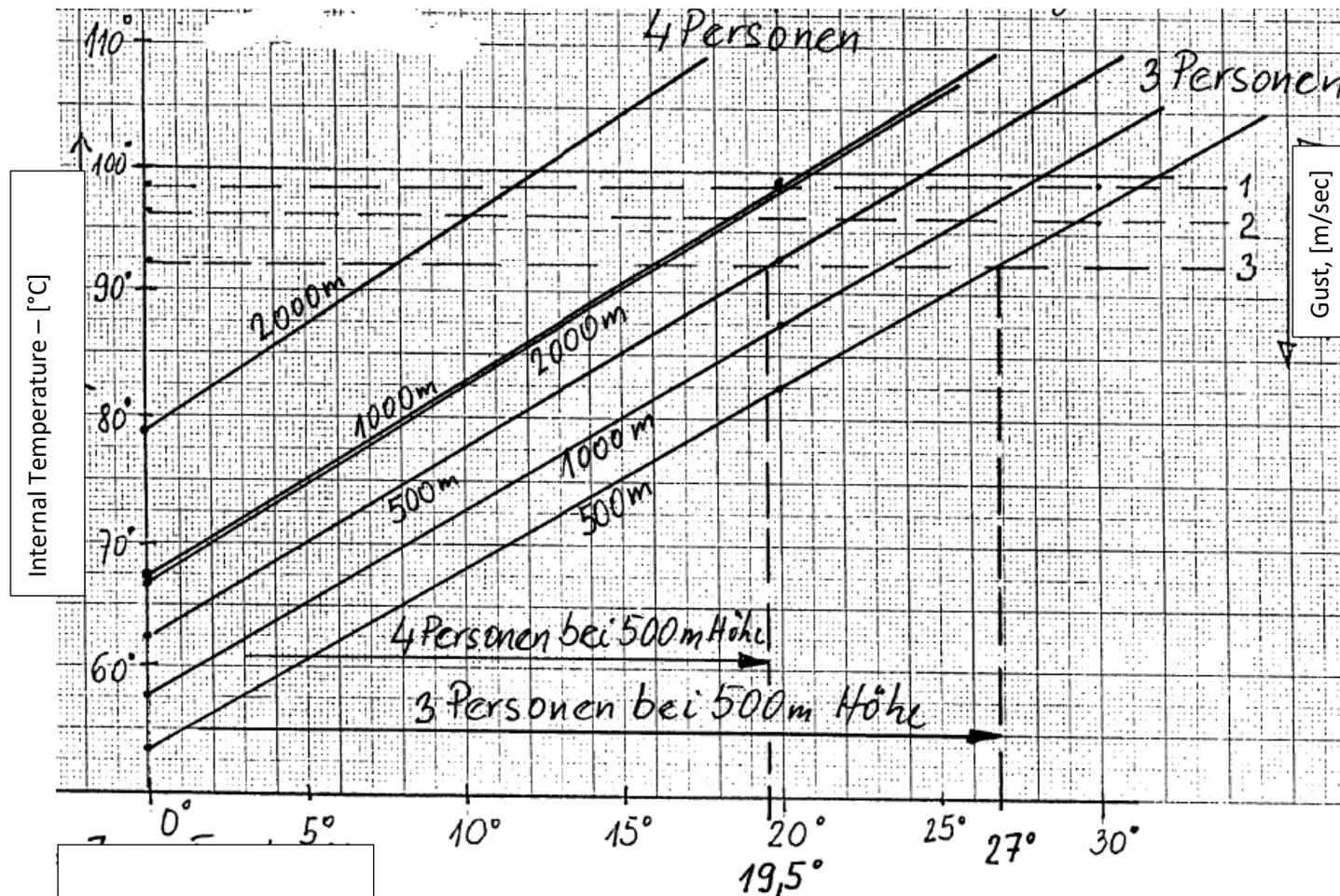1°C internal corresponds to approx. 7 kg load capacity

Diagram 4

Dependence of the internal temperature of the balloon in regards of the external temperature and load capacity

Balloon 2550 m³   Δ 1°C =~6 kg Load capacity   Based on the internal temperature

Internal Temperature [°C]

Gusts – [m/sec]

Gusts – [m/sec]

External Temperature

Abhängigkeit der Balloninnentemperatur
von der Außentemperatur und B
Ballon 2550 m³

Δ 1°C ≙ 6 kg Tragkraft
Bezogen auf die Temp. Innen

2000 m
1000 m
500 m

4 People
635 kg total

3 People
555 kg total

4 Personen

3 Personen

120°
110°
100°
90°
80°
70°
60°
50°

0° 5° 10° 15° 20° 25° 30°
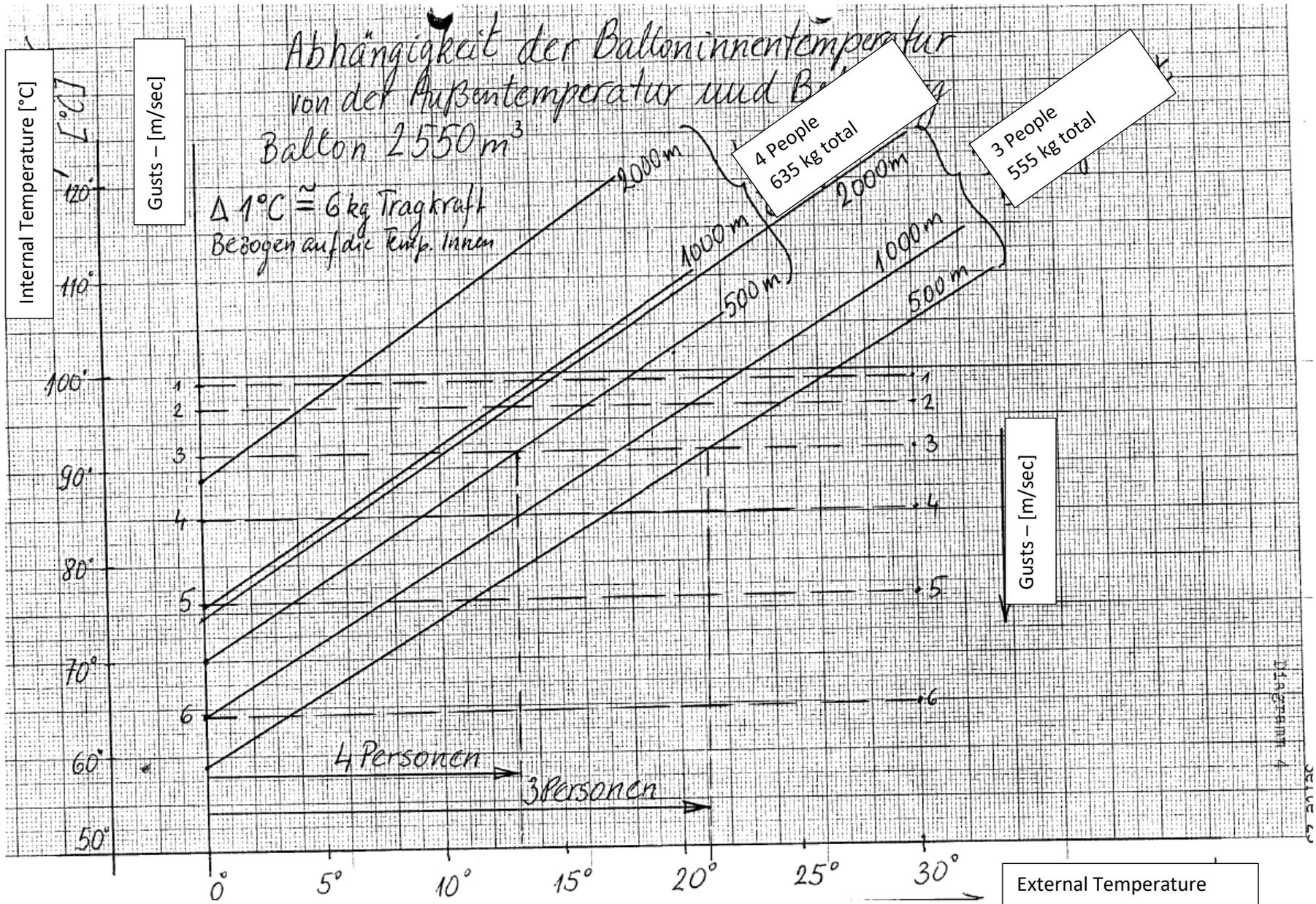
Diagram 5

Dependence of the internal temperature of the balloon in regards of the external temperature and load capacity

Balloon 2200 m³   Δ 1°C =˜ 5 kg load capacity   Based on the internal temperature

Abhängigkeit der Balloninnentemperatur von der Außentemperatur und Belastung
Ballon 2 200 m³

4 People
610 kg total

3 People
530 kg total

Δ1°C≈5kg Tragkraft
Bezogen auf die
Temperatur Innen

2000m
1000m
500m
1000m
500m

0kg

4 Personen
3 Personen

Internal Temperature [°C]
Gusts – [m/sec]
Gusts – [m/sec]
External Temperature
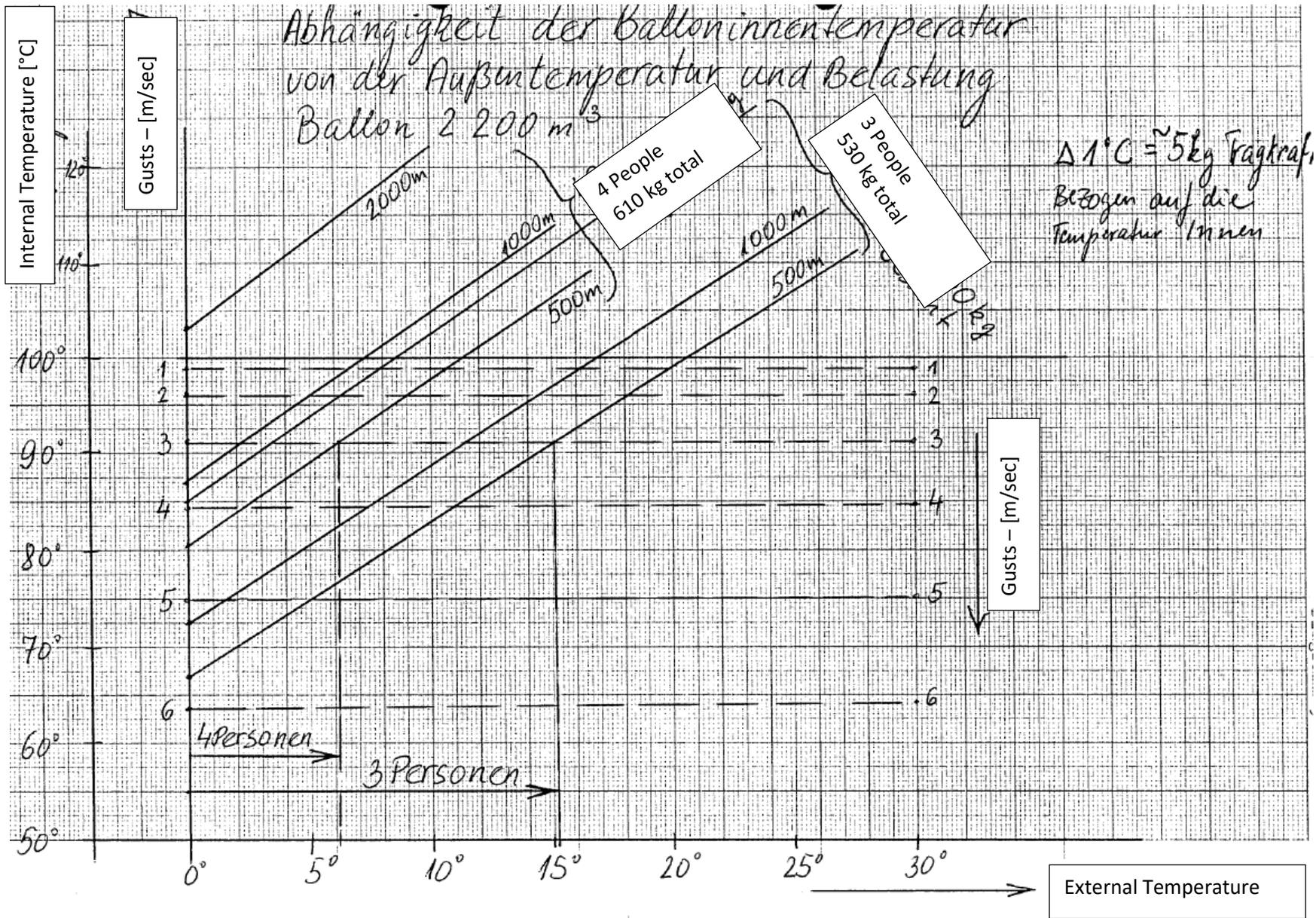
Table 6

4.2 Example of the effect of the external and internal temperature on the load capacity

Balloon 3000 m³, 500 m altitude

1.   External Temperature

elevation

from	to	Load capacity **loss** (kg)
0 °C	10 °C	168
10 °C	20 °C	120
20 °C	30 °C	111

The loss is independent of the internal temperature of the balloon.

2.   Internal Temperature

elevation

From	To	Load capacity **gain** (kg)
80 °C	90 °C	77,8
90 °C	100 °C	73,5
100 °C	110 °C	70,0

The gain is independent of the external temperature.

3. External temperature / Internal temperature

The increase in the external temperature from 0 °C to 10 °C must be countered by increasing the internal temperature from 80 °C to 93 °C. In this example the increase of the external temperature by 10 °C must be compensated by the increase of the internal temperature by 13 °C in order to achieve the same load capacity.

Chapter 5: Influence of Air Pressure on Load Capacity

Table 7

Table 7 shows the influence of air pressure on the load carrying capacity at different temperatures. In Germany the air pressure can vary between 960 hPa and 1030 hPa (in relation to sea level).
The load capacity can vary from 33 to 65 kg, depending on temperature and altitude. For each 10 hPa we lose or gain 4.7 to 9.3 kg of the total lifting capacity of the 3000 m^3 balloon. Or we need 0.8 to 1.2 °C more or less internal temperature.

Example:
      - Balloon in 3000 m^3
      - Start at 1000 m altitude
      - Temperature 20 °C   Which starting temperature?
      - Crew 4 people
      - Pressure 960 hPa

Internal temperature according to diagram 3: 97.5 °C at 1013 hPa;
53 hPa less, 6.5 kg per 10 hPa;
Reduction in load capacity: 34.5 kg : 7 = increase in internal temperature of approx. 5 °C

Start temperature 102.5 °C.

Thus, one can say very roughly that with a 3000 m^3 balloon the inside temperature changes by 1 °C per 10 hPa.

Table 7

Crew weight at below-average air pressure

Balloon 3000 m³, Internal temperature 95 °C Air pressure related to sea level

Altitude		500 m				1000 m				2000 m			
External Temperature	Load capacity	at 960 hPa (kg)	at 1030 hPa (kg)	Difference (kg)	Difference per 10 hPa (kg)	at 960 hPa (kg)	at 1030 hPa (kg)	Difference (kg)	Difference per 10 hPa (kg)	at 960 hPa (kg)	at 1030 hPa (kg)	Difference (kg)	Difference per 10 hPa (kg)
0 °C		540	605	65	9,3	489	550	61	8,7	388	442	54	7,7
10 °C		419	475	56	8	375	428	53	7,6	288	334	46	6,5
20 °C		306	354	48	7	269	314	45	6,5	194	234	40	5,7
30 °C		201	241	40	5,7	170	207	37	5,3	107	140	33	4,7

[1 hPa = 1 millibar Hg]

Chapter 6: Increasing the load capacity of the balloon through heating

Table 8
Diagram 6

Table 8 and Diagram 6 show how much additional load capacity is gained by increasing the temperature.
It is particularly important to know how load and altitude influence maneuverability.
Basically, the maneuverability deteriorates with increasing internal temperature and altitude.

We can also remember rough values; we should broadly memorize them for altitudes between 500 m and 1000 m:
- 3000 m^3 balloon --- 7 kg per °C
- 2550 m^3 balloon --- 6 kg per °C
- 2200 m^3 balloon --- 5 kg per °C   internal temperature

Example:

Start temperature of 3 persons in a 3000 m^3 balloon with 85 °C; another guest with 77 kg weight means start temperature of 77 : 7 = 11 °C more, thus 96 °C.

Next example:
An 80 kg male guest increases the necessary temperature in a 2200 m^3 balloon by 80 : 5 = 16 °C.

If you want to calculate more precisely, you can read the corresponding figures in Table 8. As can be seen from Diagram 6, these rough values for the altitude of 500 m are somewhat pessimistic with errors of 0 to 5%. We can certainly neglect these errors if we gain a quick orientation through these simple values.

We will still need these rough values in Chapter 9 for a simple determination of the heat requirement for balancing the gusts.
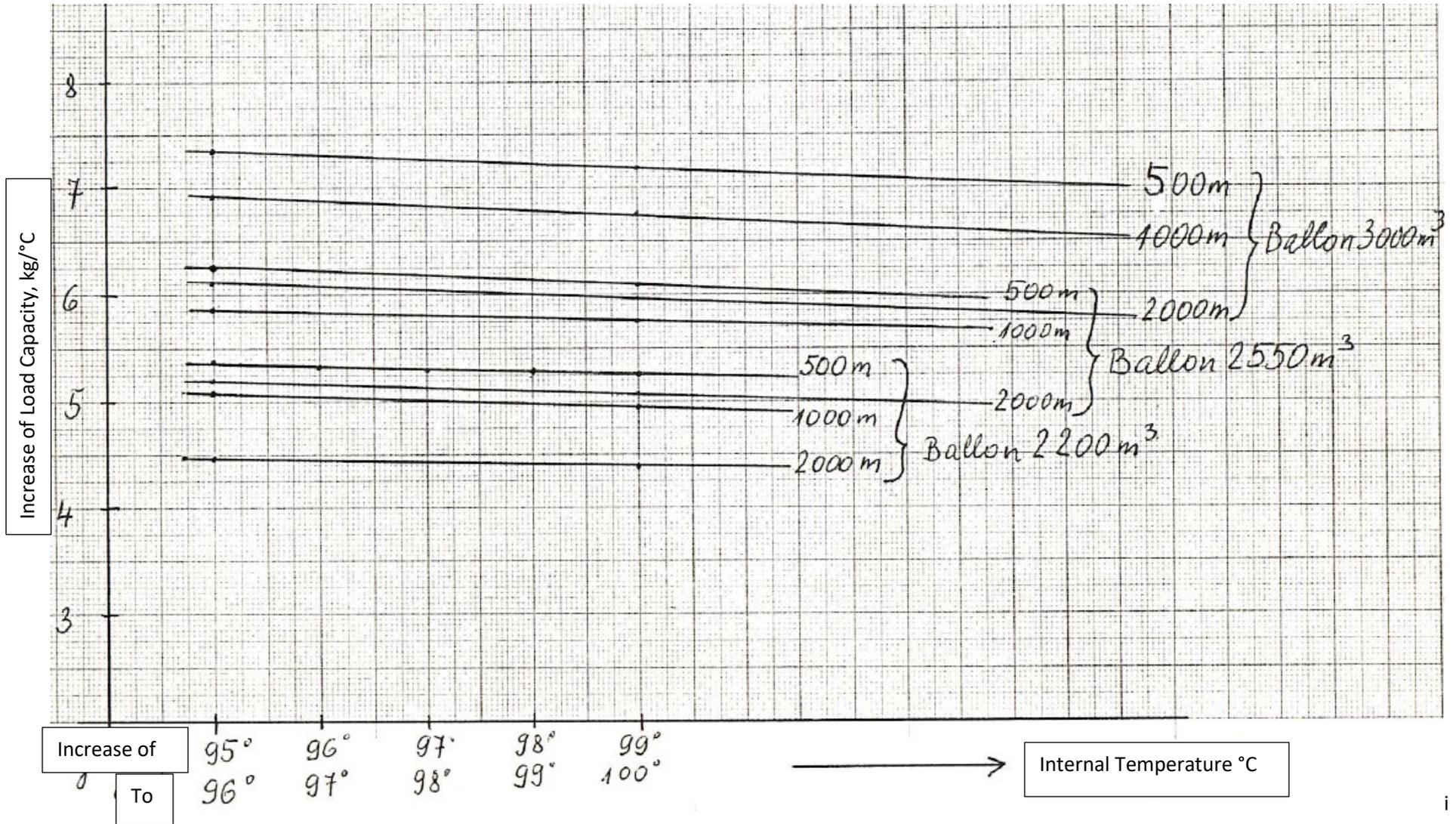
Table 8

Increasing the load capacity by increasing the internal temperature, starting from 95°C (kg)

Air pressure at sea level 1013 mPa

Temperature increase from - to	2200 m³			2550 m³			3000 m³		
	Altitude (m)			Altitude (m)			Altitude (m)		
	500	1000	2000	500	1000	2000	500	1000	2000
95° – 96°	5,39	5,07	4,48	6,24	5,89	5,20	7,35	6,92	6,11
96° - 97°	5,35	5,05	4,46	6,21	5,85	5,17	7,30	6,88	6,08
95° - 97°	10,74	10,12	8,94	12,45	11,73	10,37	14,65	13,80	12,19
97° - 98°	5,33	5,02	4,44	6,18	5,82	5,14	7,26	6,84	6,05
95° - 98°	16,07	15,14	13,38	18,63	17,55	15,51	21,92	20,64	18,24
98° - 99°	5,30	4,99	4,41	6,15	5,78	5,11	7,23	6,81	6,02
95° - 99°	21,37	20,13	17,79	24,78	23,33	20,62	29,15	27,45	24,27
99° - 100°	5,27	4,96	4,39	6,11	5,75	5,09	7,19	6,77	5,98
95° - 100°	26,65	25,09	22,18	30,89	29,08	25,71	36,34	34,22	30,25
100° - 105°	25,94	24,43	21,6	30,06	28,32	25,04	35,37	33,31	29,45
95° - 105°	52,59	49,52	43,78	60,96	57,40	50,75	71,71	67,53	59,70

Diagram 6

Increasing the load capacity by increasing the internal temperature by 1 °C (see Table 8)

Increase of Load Capacity, kg/°C

500m
1000m } Ballon 3000 m³

500 m
1000 m } 2000 m

Ballon 2550 m³

500 m
1000 m } 2000 m

2000 m } Ballon 2200 m³

Increase of	95°	96°	97°	98°	99°
To	96°	97°	98°	99°	100°

Internal Temperature °C

i

Chapter 7: Breathing of the hot air balloon during Heating and Cooling

Table 9

Heating increases the volume of the air, cooling shrinks it. Up to now, the load capacity gained or lost by this effect has been reported here. But the process has another meaning for the operation of the hot air balloon:

The expanded air needs to escape somewhere from the balloon, the shrunken air must be sucked in again somewhere. The only opening through which this air movement can be achieved is above the burner. The outflowing air moves against our flame during heating. Table 9 shows these quantities depending on the temperature increase. With a 3000 m^3 balloon, about 8 m^3 of air must escape at a temperature increase of 1 °C; with a temperature increase of 15 °C, this is a remarkable 124 m^3. In conjunction with Table 12, it is easy to calculate that to compensate for a 4 m/sec fall, it is necessary to eject 80 m^3 of air. This circumstance leads to the well-known "blocking" of the balloon, which is indicated by a sudden dull noise of the burner. Thus, you must wait a while until the extended air has escaped and then heat it again. Here we see that a too high fall velocity (or even worse a gust) brings several negative influences with it:

1. A disproportionately high-power output is necessary for the compensation.
2. A large amount of air must escape from the balloon, so the heating may have to be interrupted several times.
3. The balloon cools down very quickly due to the high relative movement of the air and the resulting convection.

Note: beyond 4 m/sec the comfort ceases.

If you think you can also heat while the balloon is "blocked", there is in fact nothing other you are doing than simply heating the outflowing air without having done anything for the actual internal temperature of the balloon. Short bursts of fire are therefore the most economical and sensible way of driving the balloon.

And one additional remark:

For the balloons with a skirt, the acoustic effect of "blocking" occurs much more strongly than for the balloons without a skirt or possibly with a scoop. However, this does not change the fact that these balloons also must eject the expanded air. If heating is not interrupted, only the outgoing air is heated and not the internal air. The fact that one or the other balloon type is better in this point is by no means correct. Rather, the expansion of the escaping air causes an additional barrier which effectively prevents any heat absorption by the balloon.

Table 9

Ejected amount of air during heating

| Temperature | | at 2550 m³ | at 3000 m³ |
From	To	(m³)	(m³)
90 °C	91 °C	7	8,2
90 °C	92 °C	14	16,5
90 °C	93 °C	21	25
90 °C	94 °C	28	33
90 °C	95 °C	35	41
90 °C	100 °C	70	83
90 °C	105 °C	105	124

Chapter 8: Propane Pressure and Burner Power

Table 10 & 11, Diagram 7

The vapor pressure of the propane/butane mixture as a function of temperature is shown in Table 10 and Diagram 7. It is important for us that the increasing butane content reduces the pressure: the mixture 50 : 50 means a pressure drop compared to pure propane as well as a temperature that is about 15 °C lower. It is well known that the evaporation heat is extracted from the remaining liquid propane when the propane gas is extracted. This heat is distributed over the volume of about 40 l (or 20 kg) in a full bottle and only a fraction of this volume in an almost empty bottle. The propane is thus cooled down relatively quickly at the end, which leads to a sharp drop in pressure for the almost empty bottles. The fact that the maneuverability of the balloon suffers is certainly known to every pilot from his own experience.

Table 11 shows some values of the burner performance that we measured with a Thunder MK II burner. Due to the pressure in the bottles and the equipment of the fittings, however, there are considerable fluctuations in performance. These values are therefore only to be understood as orientation and not as characteristic values of a burner.

For the public at an event it is certainly interesting that our burners are in the performance class between 1500 HP and 3000 HP.

Table 10

Propan % gew.	100 —	90 10	80 20	70 30	60 40	50 50	40 60	30 70	20 80	10 90	— 100	Butan % gew.
—10°	2,4	2,2	1,95	1,75	1,5	1,2	0,95	0,7	0,35	0,05	—	—10°
0	3,8	3,55	3,2	2,85	2,5	2,2	1,75	1,3	0,95	0,5	—	0
+ 10	5,6	5,2	4,7	4,3	3,8	3,35	2,8	2,25	1,7	1,1	0,45	+ 10
20	7,6	7,1	6,5	6,0	5,35	4,75	4,1	3,4	2,65	1,9	1,1	20
30	10,1	9,45	8,7	8,0	7,3	6,65	5,7	4,8	3,9	2,9	1,9	30
40	13,1	12,3	11,5	10,5	9,7	8,7	7,7	6,6	5,4	4,2	2,9	40
50	17,0	15,9	14,8	13,65	2,6	11,3	10,0	8,7	7,25	5,7	4,1	50
60	21,0	19,8	18,5	17,2	15,8	14,3	12,75	11,2	9,3	7,5	5,5	60

Vapor pressures of propane, butane and mixtures in atm.

Table 11

Temperature °C	Burner capacity kJ/sec
0°	1260
10°	1500
20°	1750
30°	2000

Performance of a single burner depending on the temperature in a propane bottle

Diagram 7

Dampfdruckkurven von Propan, Butan
und Gemisch ½ Propan und ½ Butan
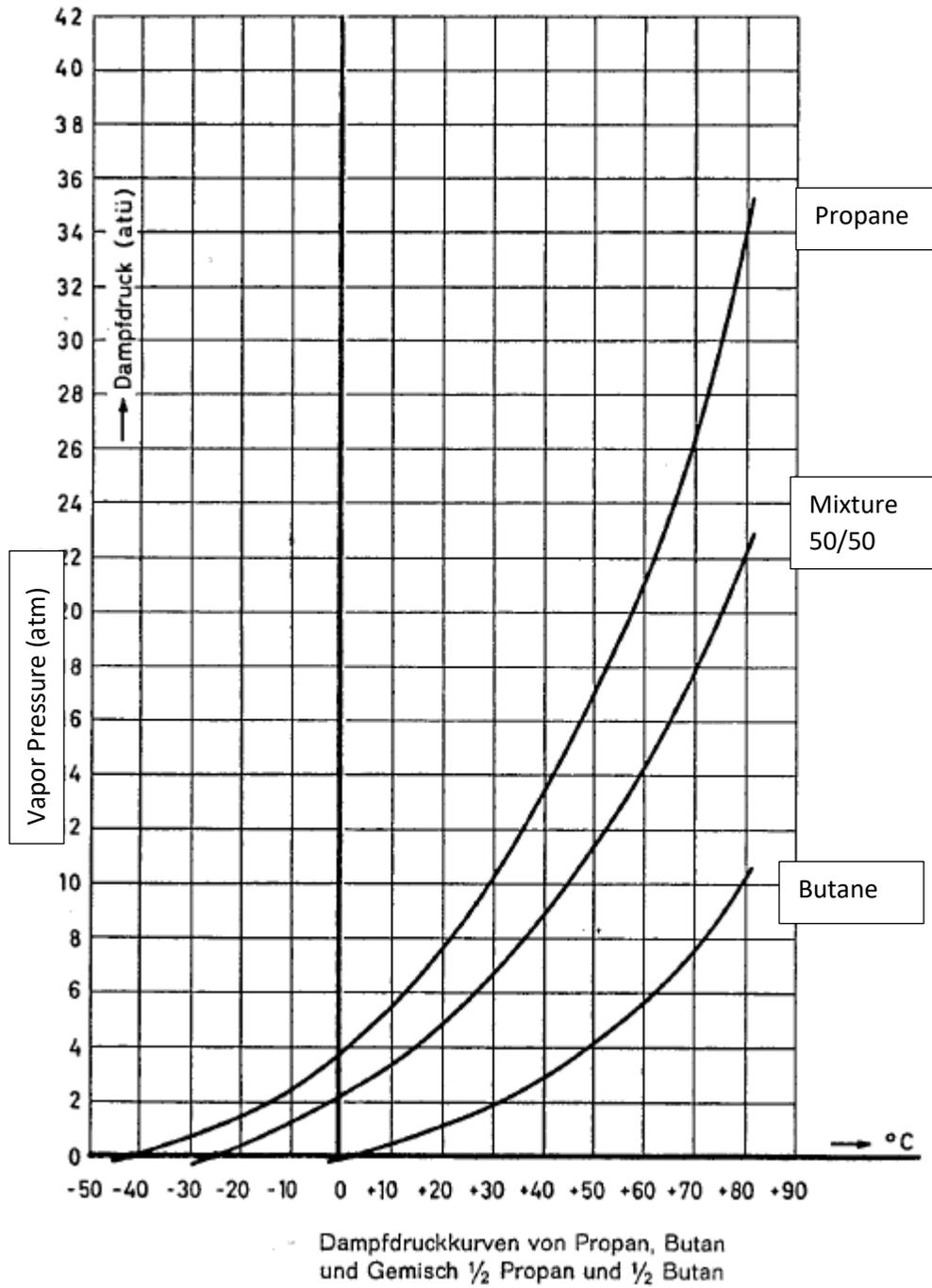
Vapor pressure graphs of propane, butane, and mixture ½ Propane and ½ Butane

Chapter 9: Relationship between falling speed, imbalance, temperature difference, heat output and heating time

Table 12
Diagram 8 & 9

The use of Table 4 and the calculation of the forces acting on an envelope leads to Table 12 and Diagram 8.

From this it can be seen how much the forces increase with the velocity of fall *[descent]* (or also with the wind force).
While in the case of 1 m/sec there is only an imbalance of 5.5 kg with a 3000 m³ balloon, this is almost 10 times the first value with 3 m/sec and 50 times the first value with 7 m/sec. However, a full hot-air balloon rarely exceeds the fall speed of 7 m/sec, as there is always a temperature difference between the external and the internal and thus there is also a residual load.

The table also shows the amount of heat and heating time required to reach equilibrium. The heating time calculation is based on an empirical determination of the burner capacity at a pressure of 8 bar. However, the actual time from the beginning of heating until equalization is considerably longer for 3 reasons:

> 1. The balloon only absorbs a certain amount of heat and then needs a pause to compensate - as already shown in Chapter 7.
> 2. The normal heat loss during heating must be compensated additionally.
> 3. This heat loss however is higher than in the balanced condition, since the air flow causes additional cooling.

These 3 additional influences are not considered in the calculation. However, it is necessary to be aware of the negative effects.

I would like to give another example of this calculation:

To compensate a gust of 4 m/sec with a fully loaded 3000 m³ balloon at 30 °C external temperature, we need 16 sec pure heating time. In practice, we will carry out 4 bursts of fire at 4 sec each with pauses of the same length, i.e. about 30 sec, in order to balance the balloon. The loss of altitude must be considered to be at least 100 m.

For driving over high voltage lines in summer, when gusts of 4 m/sec cannot be ruled out, this is certainly quite an interesting observation.

Basically, it can be said that we can compensate relatively quickly at fall speeds of up to 3 m/sec. Higher fall speeds and stronger gusts are dangerous for deep descents below 150 m altitude.

Rule of thumb:

Since the resistance coefficient of the balloon and the increase of the load capacity by raising the internal temperature by 1 °C almost coincidentally produce the same numbers, the following rule of thumb is enough for a quick orientation:

(Fall velocity)^2 = necessary increase of the internal temperature

Example: Drop with 2 m$[/sec]$ ... necessary heating by 2^2 = 4 °C
             Drop with 4 m$[/sec]$ ... necessary heating by 4^2 = 16 °C

As Table 12 shows, we do indeed need a little less, but the order of magnitude is quite in line with the rule of thumb.

Table 12

Relationship between fall velocity*[descent rate]*, imbalance, temperature difference, thermal output, and heating time

Calculated for altitude of 500 m

AT	External Temperature
IT	Internal Temperature
ΔT	Temperature difference

Fall velocity (m/sec)	Balloon with 2550 m²								Balloon with 3000 m²							
	Winter, AT 0°C, IT 80°C				Summer, AT 30°C, IT 95°C				Winter, AT 0°C, IT 80°C				Summer, AT 30°C, IT 95°C			
	Imbalance (kg)	Δ T (°C)	Heat performance (kJ)	Pure heating time (sec)	Imbalance (kg)	Δ T (°C)	Heat performance (kJ)	Pure heating time (sec)	Imbalance (kg)	Δ T (°C)	Heat performance (kJ)	Pure heating time (sec)	Imbalance (kg)	Δ T (°C)	Heat performance (kJ)	Pure heating time (sec)
1	6	0,9	1322	1,1	5,5	0,9	1225	0,8	6,8	0,85	1450	1,2	6,00	0,8	1336	0,8
2	24,5	3,6	5450	4,5	22	3,6	4900	3,1	27	3,4	5800	5	24,5	3,4	5500	3,4
3	55,5	8,4	12500	10,5	50	8,2	11300	7,1	61	7,8	13300	11	55	7,6	12500	7,8
4	98,5	15	22600	19	89	14,8	20600	13	108	14	24000	20	97,5	13,7	22500	14
5	154	24	36200	30	138	23,5	32600	20,5	169	22,5	38300	32	152,5	22	35900	22,5
6	221,5	36	53700	45	200	35	48700	30,5	243,5	33	56700	47	219.5	32,5	53100	33
7	301	50,5	75700	63	272	49,5	68600	43	331,5	47	80000	67	299	45,7	75000	47

Diagram 8

Relationship Between Fall Velocity and Heating Time

3,000 m³ Envelope Volume

2,550 m³ Envelope Volume

Pure Heating Time [sec]

300

200

100

Winter
Sommer
Winter
Sommer

2   4   5   6   7

Fall Velocity [m/sec]

Diagram 9

Relationship Between Fall Velocity and Loss of Load Bearing Capacity

Loss of Load Bearing Capacity - Kg

3,000 m³ Envelope Volume

2,550 m³ Envelope Volume

Winter

Sommer

Winter

Sommer

300

200

100

2   3   4   5   6   7

Fall Velocity, m/sec
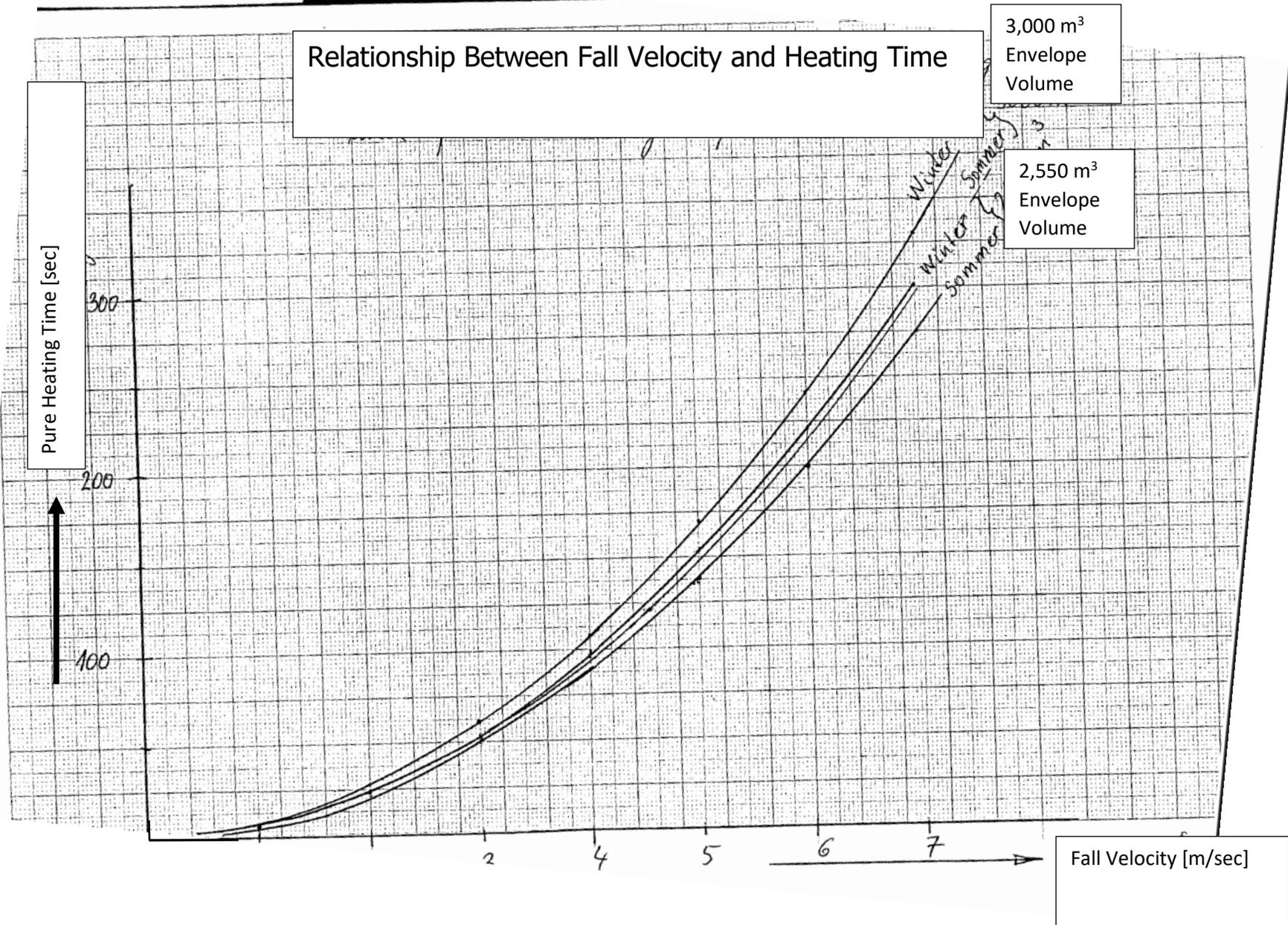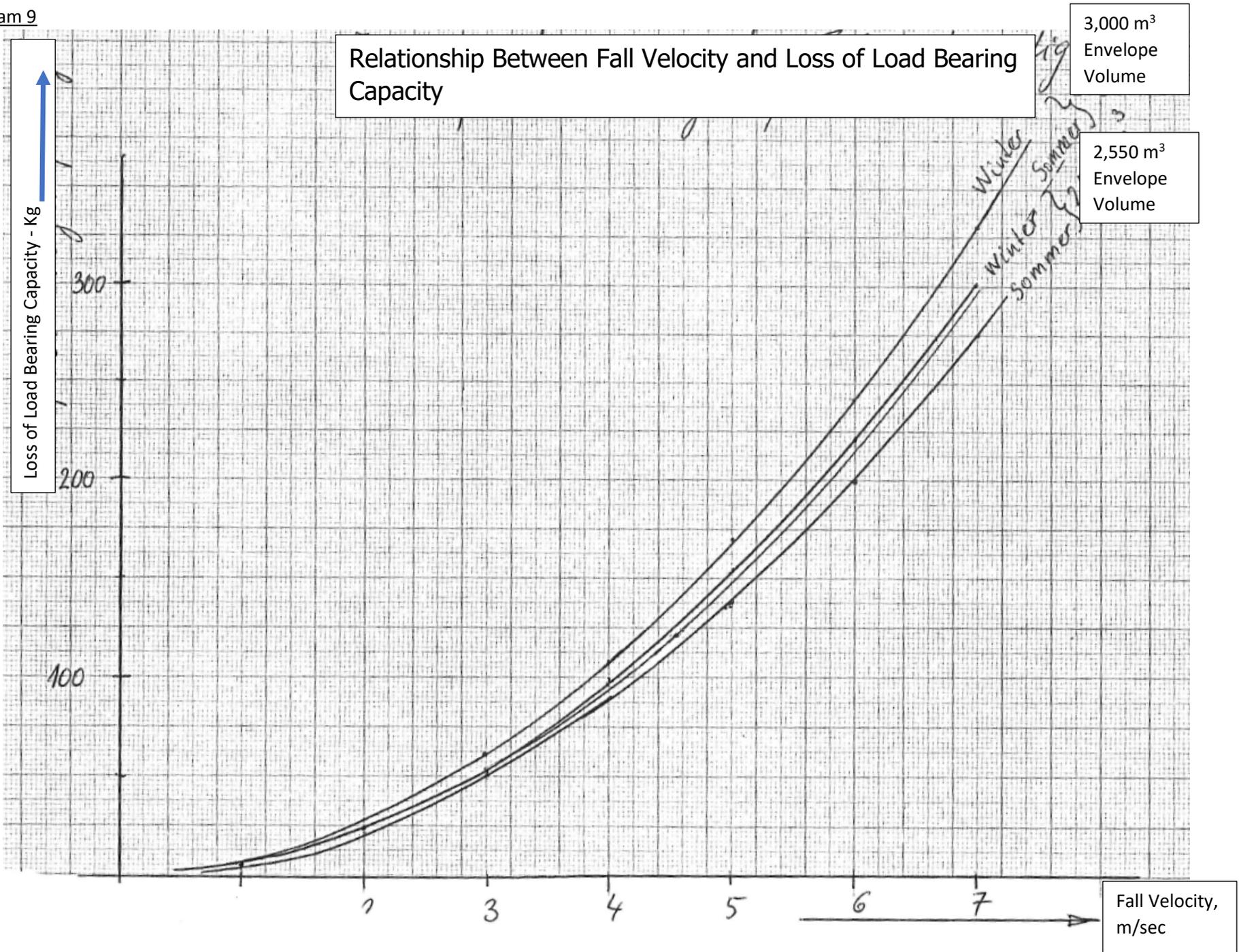
Chapter 10: Relationship between external temperature and jump height of a hot air balloon

Sketch 3
Table 13 and 14
Diagram 10

When landing a hot-air balloon, not only the energy of the wind but also the kinetic energy in vertical and horizontal direction must be eliminated. Only if we understand the interaction of these 3 energies perfectly, we can act appropriately in every situation.

10.1 Wind power

The force of the wind on the bulging balloon is shown in Table 12. The upright balloon is exposed to a wind speed of 7m/sec or about 25 km/h and a wind force of 299 kg in summer (3000 m^3 capacity assumed). By denting the balloon, this force can increase up to 3 times the value, i.e. 900 kg with the same wind speed.

Normally, such high forces cannot occur during landing, unless the balloon gets caught in an obstacle and cannot drag. In a normal dragging landing, the forces are only as great as the friction between the basket and the ground.

When a balloon is torn open, the wind forces push the air out of the envelope. Measured in units of time, a torn envelope is emptied considerably faster during a rapid landing than during a slow flight.

It is well known that 3 things are important for the crew regarding wind speed:
      1. to have enough landing area in front of them
      2. tearing **in** the air before first touchdown
      3. the crew must remain in the basket after touchdown

As simple as these rules sound, as often they are violated. Only those who plan well, place the crew in the basket sensibly and always act correctly can succeed here.

10.2 Vertical kinetic energy

The vertical kinetic energy, like the horizontal energy, is determined by half the mass and the 2nd power of the velocity of fall. When considering the landing process, we must see the energy of the basket separately from the energy of the envelope. The vertical energy of the basket is eliminated when it lands on the ground, but the energy of the envelope is not (see sketch 1): The envelope first strives towards the ground and accelerates back up again (the balloon jumps). Without effective damping the process due to a strong loss of lifting capacity, the basket is pulled up again. The jumping speed is therefore dependent on the landing speed and the ratio of the two relevant masses. The ratio of the masses is shown in the lower part of Table 4. Here the dependence on the external temperature or rather the load condition of the balloons is shown.

The values of the jump-speed and the jump height can be seen in the tables 13 and 14 and the diagram 10. The cooling of the balloon during the landing phase is already considered here. You can see that the jump height increases with the vertical landing speed.

<u>The consequence is called:</u>
The faster the descent, the more important the tearing *[venting]* of the balloon in the air before touching down.
Tearing *[venting]* before touching down at altitudes of 5 m - 10 m hardly increases the fall velocity because of the large mass of the balloon.

Here is a calculation:
<u>Example</u>: Landing with 1m/sec drop speed, 3000 m^3 balloon, start of tearing at 10 m altitude.

- Time to touch down without tearing	10 sec
- Loss of volume when tearing at an altitude of 10 m	100 m^3 (estimated)
- Loss of load capacity	ca. 25 kg
- Acceleration due to this loss	0,074 m/sec
- Increase of the velocity of fall	0,6 m/sec
- landing speed	1,6 m/sec

The loss of the content of 100 m^3 was already assumed at an altitude of 5 m above ground, i.e., in 5 sec. This value is assumed to be too high rather than too low. Therefore, the increase of the landing speed is even lower than with this calculation.

The following table provides a better understanding of the vertical landing speed and its effect:
<u>Fall speed and jump height</u>

Fall velocity on the ground (m/sec)	Corresponds to a jump from an altitude of (m)
1	0,05
2	0,2
3	0,45
4	0,8
5	1,25
6	1,8
7	2,45

As shown in the table, the usual landing speeds of up to 3 m/sec are harmless. Therefore, it is meaningless if you land vertically instead of with 1.5 m/sec, with 2 m/sec or with 2.5 m/sec. The correct altitude depends on the vertical landing speed and the construction of the tear strip. In any case: **the faster, the higher**. The fear of tearing in the air is widespread, as we can see, but wrong.

On the other hand, tearing after touching down is very dangerous, as in this case a balloon that is climbing is torn, which should be avoided at all costs. In purely mathematical terms, this corresponds to the tearing of a balanced balloon at an altitude of 14 m - 26 m (jump height in Table 10).

In addition, there are other disadvantages such as the pendulum effect when jumping. I also have calculated the kinematics of the pendulum in such a case; it leads to a cubic equation which says about the following:

The not torn balloon always rises high enough that the basket can swing through flat landing ground (our luck!). But if obstacles or small bumps are in the way, additional speeds in vertical direction of 5 m/sec and in horizontal direction of 10 m/sec are mathematically possible with a 3000 m³ balloon.

A harmless landing at 20 km/h with 2 m/sec touchdown speed can theoretically become a 55 km/h landing with 7 m/sec touchdown speed, if the topography of the landing site is unfavorable.

This shows that without using the tear*[deflation]* rope or parachute*[vent]* line before touching down the landing can be much more dangerous than with a slightly too high tear altitude.

Dynamics of a hot-air balloon that has not been torn during landing
(see Table 4)

v_L — Vertical landing speed
v_S — Vertical jump speed
m_1 — Mass of the envelope incl. hot air
m_2 — Mass of basket incl. crew

1

2

v_L

On Touchdown:
Energy of the basket is neutralized
Envelope energy remains

Energy of the jump $= \frac{1}{2} m_1 v_L^2$

v_S
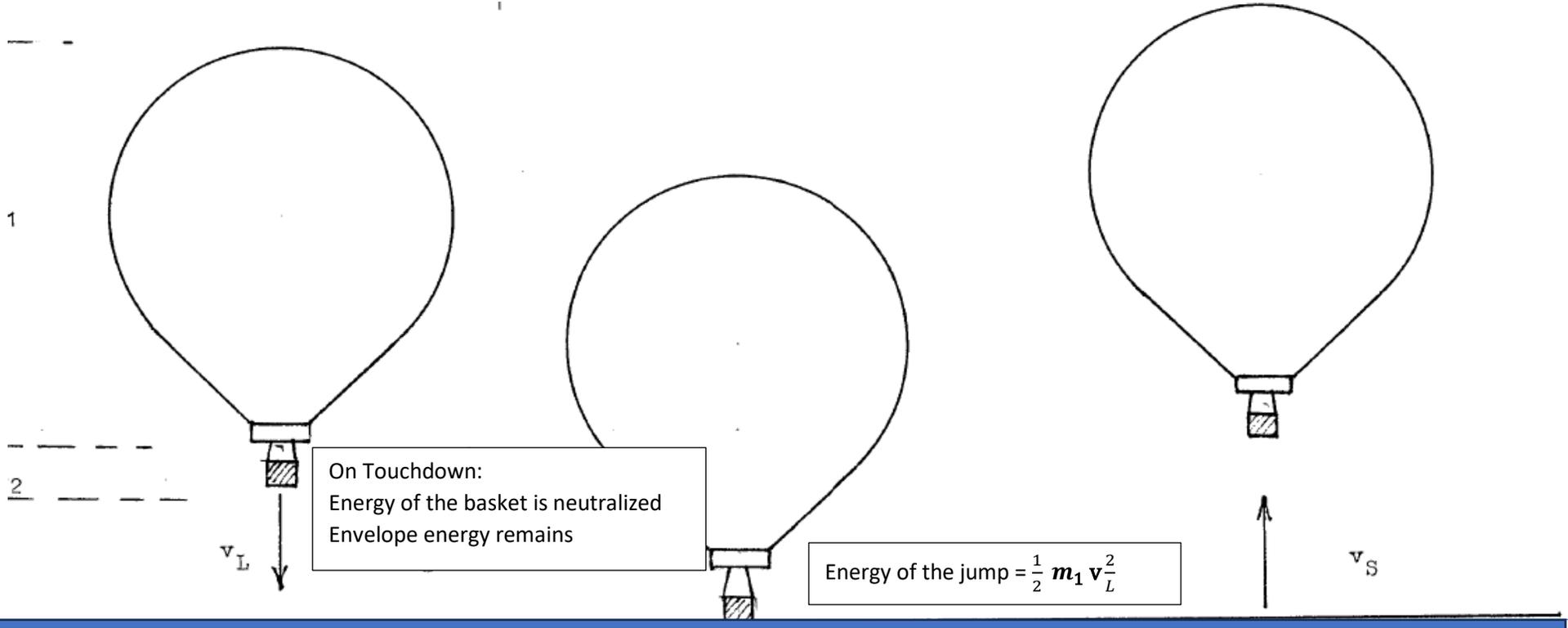
Total vertical energy:	$\frac{1}{2} m_1 v_L^2 + \frac{1}{2} m_2 v_L^2$	Es gilt: $\frac{1}{2} m_1 v_L^2 = \frac{1}{2} (m_1 + m_2) \times v_S^2$
		$v_S = \sqrt{\dfrac{m_1}{m_1 + m_2}}$

Table 13

Vertical jump speed*[Rebound Ascent rate]* and jump height*[rebound height]* of a hot-air balloon that has not been torn*[deflated/top pulled out]*

Balloon capacity: 3000 m³

Calculated with cooling of 350 kJ/sec.

T_i	Internal temperature in the balloon
G_k	Weight of basket with crew
G_h	Weight of envelope incl. hot air
G	Take-off weight of the balloon without hot air
v_a	Vertical jump speed

Landing Speed	External Temperature 0°C 4 people G = 670 kg G_k = 545 kg				External Temperature 20°C 4 people G = 670 kg G_k = 545 kg				External Temperature 30°C 3 people G = 590 kg G_k = 465 kg			
	T_i (°C)	G_h (kg)	v_a (m/s)	jump height (m)	T_i (°C)	G_h (kg)	v_a (m/s)	jump height (m)	T_i (°C)	G_h (kg)	v_a (m/s)	jump height (m)
0	61°	3111	--	--	91°	2865,5	--	--	91°	2865,5	--	--
1	60°	3120,5	0,92	4,6	90°	2873	0,92	4,93	90°	2873	0.93	5,0
2	57,5°	3143	1,85	15,6	86,5°	2900	1,83	15,9	86,5°	2900	1,86	16,3
3	53°	3184	2,77	20,7	82,5°	2931	2,75	20,66	82,5°	2931	2,79	21,3
4	47°	3242	3,7	22,9	76°	2983	3,68	22,7	76°	2983	3,72	23,5
5	38,5°	3327	4,63	24	68°	3050	4,6	23,8	68°	3050	4,66	24,6
6	28°	3439	5,57	25	57,5°	3143	5,54	24,8	57,5°	3143	5,6	25,7
7	14°	3601	6,52	26,7	44°	3271	6,48	26,0	44°	3272	6,55	26,9

Table 14

Vertical jump speed*[Rebound Ascent rate]* and jump height*[rebound height]* of a hot-air balloon that has not been torn*[deflated/top pulled out]*

Balloon capacity: 2550 m³

Calculated with cooling of 350 kJ/sec.

T_i	Internal temperature in the balloon
G_k	Weight of basket with crew
G_h	Weight of envelope incl. hot air
G	Take-off weight of the balloon without hot air
v_a	Vertical jump speed

Landing Speed, m/sec	External Temperature 0°C 4 people G = 635 kg G_k = 535 kg				External Temperature 20°C 3 people G = 555 kg G_k = 455 kg				External Temperature 30°C 2 people G = 475 kg G_k = 375 kg			
	T_i (°C)	G_h (kg)	v_a (m/s)	jump height (m)	T_i (°C)	G_h (kg)	v_a (m/s)	jump height (m)	T_i (°C)	G_h (kg)	v_a (m/s)	jump height (m)
0	70°	2572	--	--	89°	2442	--	--	91°	2429	--	--
1	69°	2579	0,91	4,02	88°	2449	0.92	4,25	90°	2435	0,93	4,3
2	66,5°	2597	1,82	11,9	85,5°	2465	1,84	14,47	87,5°	2452	1,8 6	14,9
3	61,5°	2635	2,73	18,5	81°	2495	2,76	19,03	83°	2482	2,8	19,6
4	55°	2685	3,65	20,6	74°	2543	3,68	21,1	76°	2529	3,7	21,7
5	46°	2758	4,57	21,9	65,5°	2604	4,61	22,4	67,5°	2590	4,7	23
6	34°	2862	5,5	23,1	54°	2693	5,55	23,3	56°	2677	5,62	24
7	19,5°	2999	6,45	24,5	39,5°	2813	6,49	24,7	41,5°	2796	6,57	25,27

Diagram 10

Interactions between the fall velocity*[descent rate]* and the jump height*[rebound height]* of a hot-air balloon that has not been torn*[deflated/ripped out]*

(see Tables 13 and 14)

Legend:
- 3000 m³, 30°, 3 people (summer)
- 3000 m³, 0°, 4 people (winter)
- 2550 m³, 30°, 2 people (summer)
- 2550 m³, 0°, 4 people (winter)

Y-axis: Jump Height [m]

X-axis: Fall Velocity [m/sec]
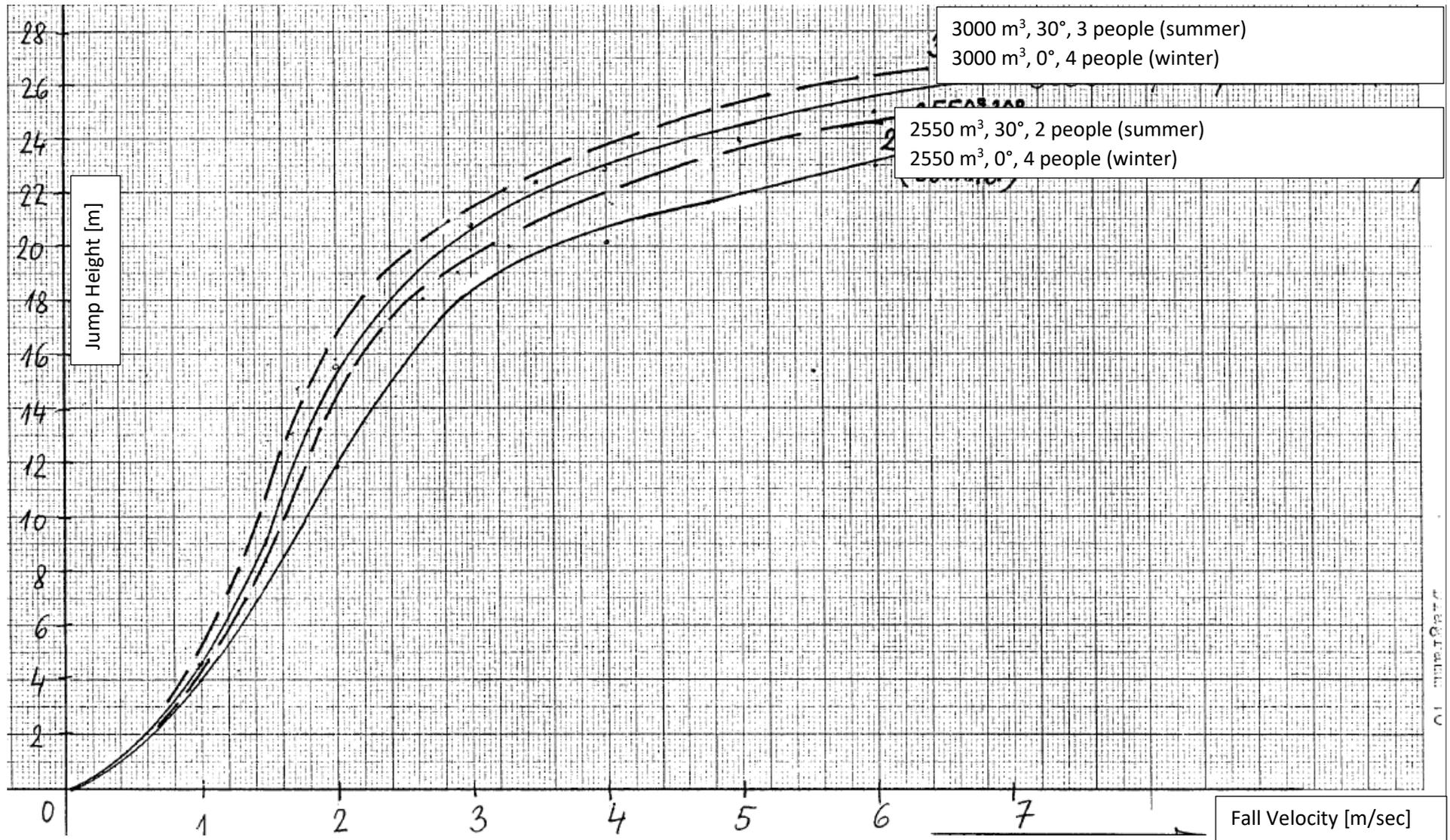
Conclusion

The calculations carried out here are intended to provide a better understanding of the interrelationships that accompany us when driving a hot air balloon. Like every calculation, it usually works with one variable, whereby the other variables are converted into constants.

In practice, all these variables work together:
With the altitude not only the specific weight of the air changes, but mostly also the external temperature. The weight of the basket decreases during the ride. The topography, the houses and the power lines play a role that is not good for us. The pilot should also read the map, use the radio, brief, and entertain guests and, last but not least, enjoy the beautiful ride.

In order to be able to do all this right all at once, we should spare no effort to better understand the matter we deal with. It helps us to make the right decisions at the right moment – in advance.

Dipl. Ing.
Pavel Hora
Im Haldenrein
7014 Kornwesthein
West Germany
October 1988

Appendix

- Calculation formula

- Table of the altitude from the pilot's manual, Schroeder Fire Balloons

- *[FAI Sub-Class Sizes for Balloons]*

- Stuttgart Balloon Club, Club Balloon Flight Record

Calculation Formula

Regarding Tables 1, 2, and Diagram 2

Specific air weights external and internal, Specific load capacity

$$\gamma_A = \frac{1{,}293}{n} \cdot \frac{273}{T_A}$$

$$\gamma_i = \frac{1{,}293}{n} \cdot \frac{273}{T_i}$$

$$t = \frac{1{,}293}{n} \cdot 273 \left(\frac{1}{T_A} - \frac{1}{T_i} \right)$$

Regarding Table 4 Relevant weights of the hot air balloon

$$G = V \cdot t$$

$$G_B = V \cdot t - G_L$$

$$G_{ges} = G_B + G_K$$

$$G_h = \gamma_i \cdot V + G_o$$

Regarding Table 5 and Diagrams 3, 4 and 5

Temperature in the balloon depending on the crew, external temperature and altitude

$$T_i = \frac{273 \cdot V \cdot \gamma_o \cdot T_A}{V \cdot \gamma_o \cdot 273 - G \cdot n \cdot T_A}$$

Regarding Table 7   Weight of crew at various air pressures at 95°C

$$G_n = V \cdot t \cdot \frac{p_x}{p_o} - G_L$$

Regarding Table 8   Gaining load capacity by increasing the internal temperature

$$\Delta G = 273 \cdot \frac{\gamma_o}{n} \cdot \left(\frac{1}{T_{i1}} - \frac{1}{T_{i2}} \right) \cdot V$$

Regarding Table 9   Ejected air mixers during heating

$$\Delta V = \left(\frac{T_{i2}}{T_{i1}} - 1 \right) \cdot V$$

Table 11   Burner capacity
Determined experimentally

Table 12 Diagrams 8 and 9
Relationship between velocity of fall, imbalance, temperature difference, heat output and heating time

a)
$$\Delta P_s = c_w \cdot A \cdot \frac{\gamma_A}{2 \cdot g} \cdot v^2$$

$c_w = 0,47$

$A = 232 \text{ m}^2$ bei 3000 m^3

$A = 211 \text{ m}^2$ bei 2550 m^3

b)
$$\Delta T = \frac{T_i^2 \cdot \Delta P_s \cdot n}{\gamma_o \cdot T_o \cdot V - \Delta P_s \cdot n \cdot T_i}$$

c)
$$W = \Delta T \cdot V \cdot c_p$$

d)
$$c_p = c_{po} \cdot \frac{T_o}{n \cdot T_i}$$

e)
$$H_z = \frac{W}{L_B} + \frac{W}{L_B} \cdot \frac{350}{L_B} = \frac{W}{L_B} \cdot \left(1 + \frac{350}{L_B} \right)$$

Tables 13 and 14, Diagram 10

Vertical jump speed of a hot-air balloon that has not torn, the jump height

$$v_a = v_L \sqrt{\frac{m_1}{m_1 + m_2}}$$

$$h = \frac{v_a^2 \cdot (G_h + G_{BK})}{2 \cdot g \cdot \left[\Delta P_s + \frac{r_o}{n} \cdot V.273 \cdot \left(\frac{1}{T_i - \frac{20.W}{c \cdot W \cdot W}} - \frac{1}{T_i} \right) \right]}$$

Definition of Variables:

Y_A	Specific weight of outdoor air (kg/m3)
Y_i	Specific weight of indoor air (kg/m3)
n	Altitude
T_A	Outdoor temperature (°K)
T_i	Internal temperature (°K)
t	Specific load capacity (kg/m3)
G	Take-off weight of the balloon without hot air with crew (kg)
G_{PK}	Weight of basket with crew (kg)
G_K	Weight of basket without crew (kg)
G_h	Weight of the envelope with hot air (kg)
G_o	Weight of empty envelope (kg)
V	Volume of the balloon (m3)
G_B	Weight of crew (kg)
G_L	Weight of the balloon without crew
P_x	Actual air pressure, relative to sea level (hPa)
P_o	1013 hPa
T_{i1}	Initial temperature in the envelope (°K)
T_{i2}	Final temperature in the envelope (°K)
Δ_G	Increase in load capacity during heating (kg)
Δ_V	Volume increase by heating (m3)
Δ_{Ps}	Stationary imbalance (kg)
Δ_{PL}	Imbalance due to continuous cooling
Δ_{PG}	Total imbalance (kg)
Δ_T	Temperature difference when the balloon sinks (°K)
W	Specific heat loss of the balloon (kJ/sec)
c_p	Specific heat of the air (kJ/m3 °K)
c_{po}	0.779 (kJ/m3 °K) at 1013 hPa and 0 °K
c_w	resistance coefficient
A	Effective area
g	Acceleration due to gravity (m/sec2)
v	Velocity of fall (m/sec)
v_L	Vertical landing speed (m/sec)
v_a	Vertical jump speed (m/sec)
h	Jump height (m)
m_1	Mass of envelope including hot air (kp.sec2/m)
m_2	Mass of the basket including crew (kp.sec2/m)
E_G	Total kinetic energy of the balloon (kpm)
E_H	Kinetic energy of the envelope including hot air (kpm)
E_K	Kinetic energy of basket inclusive crew (kpm)
L_B	Burner capacity (kJ/s)
H_z	Heating time (sec)

2.1.1.1   Sub-class AA: Free balloons, not equipped with an airborne heater, which obtain their buoyancy from a lighter-than-air gas, without pressurisation of the envelope.

2.1.1.2   Sub-class AX: Free balloons which obtain their buoyancy solely as a result of heating air. The envelope may contain no gases other than air and the normal products of combustion.

2.1.1.3   Sub-class AM: Free balloons which use both a lighter-than-air gas and an airborne heater, without pressurisation of any envelope.

2.1.1.4   Sub-class AS: Free balloons which use a lighter-than-air gas and are designed to allow sufficient pressurisation of the envelope to affect performance substantially.

2.1.1.5   Sub-class AT: Free balloons not falling into subclasses AA, AX, AM or AS.
A free balloon which obtains its buoyancy as a result of heating air using solar and/or external radiation sources only may be included in this sub-class.

2.1.2   SUB-CLASS SIZE CATEGORIES

For each sub-class the size categories are the following:

250 m^3 and less		AA-1	AX-1	AM-1	AS-1	AT-1
250 m^3 to 400 m^3	AA-2	AX-2	AM-2	AS-2	AT-2
400 m^3 to 600 m^3	AA-3	AX-3	AM-3	AS-3	AT-3
600 m^3 to 900 m^3	AA-4	AX-4	AM-4	AS-4	AT 4
900 m^3 to $1\,200 \text{ m}^3$	AA-5	AX-5	AM-5	AS-5	AT-5
$1\,200 \text{ m}^3$ to $1\,600 \text{ m}^3$	AA-6	AX-6	AM-6	AS-6	AT-6
$1\,600 \text{ m}^3$ to $2\,200 \text{ m}^3$	AA-7	AX-7	AM-7	AS-7	AT-7
$2\,200 \text{ m}^3$ to $3\,000 \text{ m}^3$	AA-8	AX-8	AM-8	AS-8	AT-8
$3\,000 \text{ m}^3$ to $4\,000 \text{ m}^3$	AA-9	AX-9	AM-9	AS-9	AT-9
$4\,000 \text{ m}^3$ to $6\,000 \text{ m}^3$	AA-10	AX-10	AM-10	AS-10	AT-10
$6\,000 \text{ m}^3$ to $9\,000 \text{ m}^3$	AA-11	AX-11	AM-11	AS-11	AT-11
$9\,000 \text{ m}^3$ to $12\,000 \text{ m}^3$	AA-12	AX-12	AM-12	AS-12	AT-12
$12\,000 \text{ m}^3$ to $16\,000 \text{ m}^3$	AA-13	AX-13	AM-13	AS-13	AT-13
$16\,000 \text{ m}^3$ to $22\,000 \text{ m}^3$	AA-14	AX-14	AM-14	AS-14	AT-14
Above $22\,000 \text{ m}^3$	AA-15	AX-15	AM-15	AS-15	AT-15

2.1.3   DETERMINATION OF CUBIC CAPACITY

The cubic capacity of a free balloon shall be calculated from the geometric form of every part of the balloon system when it has the greatest volume which it can achieve in flight without elastic extension. If the material of the balloon has sufficient elasticity that the actual volume achieved in flight would affect the size category, then that volume must be used. The volume shall be determined in figures rounded to the nearest cubic metre.

- *[From FAI Sporting Code, Sectioni 1 – Aerostats. /https://fai.org/sites/default/files/sc01_april_2021_final.pdf]*

Balloon Flight Manual / Fundamentals of Ballooning

aus: Handbuch für Freiballonpiloten/Grundlagen der Ballonführung
Reg. Nr. 17, s. 14 f

[Ref.1 & 2]

Tabelle 3 : Höhenzahl n und zugehörige Höhe in m

Hundertstel von n:

n	0	1	2	3	4	5	6	7	8	9
1,0.	0	79	158	236	313	390	466	541	615	689
1,1.	762	834	906	977	1047	1117	1186	1255	1323	1390
1,2.	1457	1524	1590	1654	1718	1782	1846	1910	1973	2035
1,3.	2097	2158	2219	2279	2338	2397	2456	2515	2573	2631
1,4.	2688	2745	2802	2858	2913	2969	3025	3080	3134	3187
1,5.	3240	3293	3346	3398	3450	3502	3553	3604	3655	3705
1,6.	3755	3805	3854	3903	3952	4001	4049	4098	4146	4193
1,7.	4239	4286	4333	4379	4425	4471	4517	4563	4608	4653
1,8.	4698	4742	4786	4829	4872	4916	4959	5002	5045	5088
1,9.	5130	5172	5213	5255	5296	5337	5378	5419	5459	5499

Zehntel von n:

n	0	1	2	3	4	5	6	7	8	9
2,	5539	5929	6301	6656	6996	7321	7636	7936	8227	8508
3,	8779									
4,	11078									
6,	14318									
8,	16617									
10,	18399									
15,	21639									
20,	23938									

Tabelle 3 a : Höhe und zugehörige Höhenzahl

Höhe (m)	0	100	200	300	400	500	600	700	800	900
0	1,000	1,013	1,025	1,038	1,051	1,065	1,078	1,092	1,105	1,119
1000	1,133	1,148	1,162	1,177	1,191	1,206	1,222	1,237	1,253	1,268
2000	1,284	1,300	1,317	1,334	1,351	1,367	1,385	1,402	1,420	1,438
3000	1,456	1,474	1,492	1,511	1,530	1,550	1,569	1,589	1,609	1,629
4000	1,650	1,670	1,692	1,713	1,735	1,756	1,778	1,800	1,823	1,846
5000	1,870	1,893	1,917	1,941	1,965	1,990	–	–	–	–

Ref #1 : Balloon Pilot Flight Manual , Schroeder Fire Balloons, 1985 , https://schroederballon.de/en/hot-air-balloon-start/

Ref #2: Fundamentals of Ballooning, 1910. Republished by Kessinger Publications 10Setp2010, ISBN-10 # 1168378885, ISBN-13 # 978-11689378880

Freiballon
Fahrtbericht Nr.   **Größe**   **m³,**   **Füllung**   **Ballonsportgruppe Stuttgart**

Aufstiegstag	Zweck der Fahrt
Startort	Landeort

Startzeit	Landezeit	Betriebszeit	Std.	Min.	Fahrtzeit	Std.	Min.

Fahrtstrecke km,	Luftlinie km,	Höchste Höhe über NN	Meter

Höchste Geschwindigkeit km,   Durchschn. Geschwindigkeit (Luftl.)   km/h (Fahrtl.)   km/h

Landeart: Ventil   , Reißbahn   ,   Zwischenlandungen

Verantw. Pilot

Co. Pilot

Ballonmeister   Starter

Etappen-Nr.	Besondere Ereignisse Materialbeschädigung	Gef. km	Gef. h/m	Geschw. km/h

Zeit	Ortsbestimmung	Höhe NN	Ball Gas	Geschw. km/h	Temp./i.a. Temp./Feucht.	Fahrt-richt.	Wetter-Bemerkungen