High Altitude Tandem Parachute Descents

What is the Safest Maximum Height?

How High is To High?

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Introduction

Tandem parachuting in recent years has developed from a sport and recreational activity into a highly completive commercial adventure activity. The inevitable commercial pressures to provide a "point of difference" has resulted in the commercial tandem market offering higher altitudes to tandem riders more common. The introduction of larger turbine aircraft that can operate at much higher altitudes than was previously "normally" used in parachuting over the last few years has made "high altitude" or parachute descents over 13000ft AMSL become a normal activity in New Zealand.

There are two pieces of legislation that primarily cover this activity, these being;

1. The Civil Aviation Act 1990.
   - To establish rules of operation and divisions of responsibility within the New Zealand civil aviation system in order to promote aviation safety;
2. The Health and Safety Act 1992.
   - The Health and Safety in Employment Act's object is to promote the prevention of harm to all persons at work and other persons in, or in the vicinity of, a place of work.

Prior to 2007 regardless of the Civil Aviation Rule requirements tandem parachute descents had been limited to a maximum of 16500ft AMSL by the fact that all parachutists and parachute operators were required to comply with one set of operating set of standards in New Zealand. With the introduction of competition however parachute operators since 2007 now have a choice and as such different standards are now available within the Civil Aviation Rule structure.

Irrespective of which operational standard a parachute operator chooses to operate under or the requirements of any particular Civil Aviation Rule, the Health and Safety Act requires the operator to take all practicable steps in managing any hazards.

Where two pieces of legislation apply to any given situation, an employer or any other person affected needs to follow both. In effect, meeting the requirements of the other legislation will usually mean that the requirements of the Health and Safety in Employment Act are being met in relation to the particular hazards covered.

Many of the duties in the Health and Safety in Employment Act are qualified by the words "take all practicable steps".

This phrase applies to the general duties that must be carried out by employers, employees, self-employed people, people who control places of work, and "principals", who are people who engage contractors to carry out work for them.

The Act specifies that a person is required to take those steps only in respect of circumstances that the person knows or ought reasonably to know about.

Where the circumstances are known, or ought reasonably to be known about, the duty holder is required to take all steps that are **reasonably** practicable. A step is practicable if it is possible or capable of being done. Whether a step is also reasonable takes into account:

• The nature and severity of any injury or harm that may occur;

• The degree of risk or probability of injury or harm occurring;

• How much is known about the hazard and the ways of eliminating, isolating or minimising the hazard; and

• The availability and cost of safeguards.

The degree of risk and severity of potential injury or harm must be balanced against the cost and feasibility of the safeguard. The cost of providing safeguards has to be measured against the consequences of failing to do so. It is not simply a measure of whether the person can afford to provide the necessary safeguards. Where there is a risk of serious or frequent injury or harm, a greater cost in the provision of safeguards may be reasonable.

Given the responsibility of the legislation is borne on the operator it is therefore not the authors intention to make any conclusions regarding the current limitations set by Civil Aviation Rules or other legislation.

There are number of safety areas that this report will focus on, they are in no way all the areas that any operator or participant should consider and by no means should they be considered the only safety considerations.

All tandem skydiving involves a certain amount of risk, at one level this is considered an acceptable level and is recognised within the adventure industry in New Zealand. In 1996 90% of tandem skydives in New Zealand were made from 10000ft AMSL or lower, by 2006 that figure had changed. By this time 80% of the tandem skydive market in New Zealand was completed at operations that had the ability to ascend to 13000ft AMSL. Today 80% of the 75000 commercial tandems completed annually in New Zealand are completed at operations that have the ability to ascend to 16500ft AMSL and there is at least one New Zealand operator now offering Tandem Skydives from 19000ft AMSL.

Primarily this report focuses on the increased risk in tandem parachute descents above 13000ft AMSL that do not exist below 13000ft AMSL.

This information and report therefore focuses on these areas:

1. **The altitude - the effects of altitude on the human body and parachute equipment.**
2. **The opening of the parachute- the effects on the equipment at altitude and the human body.**
3. **The equipment used for parachutists for the supply of oxygen in the aircraft.**

The altitude - the effects of altitude on the human body and parachute equipment.

Parachute descents below 13000ft ASL are not required to carry any oxygen regardless of how long the parachute aircraft is above 10000ft AMSL. This differs from the aircraft pilot in that the rules covering the PIC are covered by separate CAR. Most parachute descents fall into this category in NZ.

Parachute jumps above 20000ft AMSL are required to use oxygen during the accent and descent until such time as the parachutist is below 13000ft AMSL. Few parachute jumps are in this category at this stage.

This leaves the issue with parachute descents between 13000ft and 20000ft AMSL. An increasing number of parachute jumps are in this area.

The difference and effects of altitude between 13000ft and 20000ft AMSL is significant and the question is raised as to where in this range is the risk significantly increased.

Altitude and hypoxia.

Medical experts agree that 15000ft AMSL is the height at which the risk significantly increases. Below this height the risk of hypoxia and being significantly affected by altitude is minimal if you are exposed to altitudes below this height for short periods of time even without supplementary oxygen. The longer you spend above this altitude and the higher you go above this altitude the higher the risk and the more likely that altitude will affect the ability for a person to be effective in their ability to be able to make effective safe decisions at critical times and the more dangerous it is to the individual. The dangers increase not only for the Tandem Master but also for the unprotected unqualified, untested tandem rider.

This height is backed by medical experts worldwide as can be seen by the following information from medical journals. The following is taken from the "Fundamentals of Aerospace Medicine By Jeffrey R. Davis, Robert Johnson, Jan Stepane". And from Fundamentals of Aviation Medicine by A. A. Lavincof to name just two.

Below 10000 ft few normal individuals notice hypoxic symptoms' while at rest, although measurable deficiencies in night vision and colour exist. Depending on the individual, scotopic visual function may be reduced by approximately 10% at 5000ft and 28% at 10000ft. From altitudes of 1000ft to 15000ft cardiorespiratory function will allow the acclimatised individual to function, typically for an indefinite period of time. Nonetheless, some degree of impairment in the rule with decreased alertness and impaired judgement and co-ordination. Above approximately 15000ft the un-acclimatized individual will usually *become severely impaired usually within minutes or even seconds, depending on the altitude. However it should be noted that individual tolerances vary markedly. The length of time an individual is able to perform useful flying duties is known as the effective performance time, (EPT) or time of useful consciousness (TUC). This does not reflect the onset of unconsciousness per se – at 18000ft, for instance might not reach such a state – but rather the period of time beyond which the aviator would be unlikely to take corrective or preventative action.*

Exercise even at modest levels shortens the EPT because decreased circulation time increases peripheral demand resulting in faster loss of oxygen.

Given there is no requirement for a parachutist to carry supplementary oxygen under the descent phase of the jump, the medical information indicates that 15000ft as the safe ceiling for non-oxygen assisted parachute descents.

The question then is raised as to how the individual is affected should the individual or tandem pair ascend above 15000ft towards 20000ft and to what effect would it have?

Again the medical experts report the following information.

Signs and Symptoms of Hypoxia

The warning symptoms of hypoxia tend to be subtle, and the symptom onset insidious. Recognition of developing hypoxia is also hampered by the fact that the cognitively impaired individual has difficultly recognising his or her own cognitive impairment; and example is the intoxicated driver who is convinced that he is in full control of his vehicle. Therefore, considerable attention should be devoted to acquainting the aviator with the early warning signs of hypoxia.

The affects listed in the medical information that are of concern are numerous and some are as follows;

The concept of "altitude sickness" combines a number of functional defects in the organism, especially in the central nervous system, which occur under conditions of oxygen starvation.

Characteristic features of altitude sickness are the following: initially there is an excited state and an uplifting of spirits, followed by a feeling of warmth in the face and a flow of blood to the head, dyspnea, headache, nausea, weakness, somnolence, indifference to surrounding events, disruption of attention, slowing down of response reactions to external stimuli, difficulty in carrying out counting operations, decrease in working ability, disruption of fine coordinated movements and handwriting, a feeling of cold in the extremities, paleness or blueness of the cutaneous coverings , dizziness , nausea, and sometimes vomiting. In serious cases , loss of consciousness occurs, and if measures are not taken depth may ensue from paralysis of the respiratory centre.

If an individual making an ascent does not use oxygen apparatus or for some reason the supply of oxygen is cut off, the first signs of altitude sickness sometimes appear as early as 2500 -3000 m. At 4000 -4500m these symptoms become quite pronounced in most people. As indicated by experience with "ascents" in a barochamber, a stay at an altitude of 5000 m and respiration for the first 30 minutes of atmospheric air in certain healthy persons may cause the development of altitude sickness in a serious form, making it necessary to "descend" to a lower altitude or to stop the test. At an altitude of 6000 m an altitude sickness in this form develops much more frequently and becomes dangerous for life.

Altitude sickness follows one law: the greater the altitude, the more rapidly and severely it develops.

The principal danger of altitude sickness lies in the fact that the flow of psychic processes is interrupted first of all. The individual cannot evaluate his own condition and the surrounding situation in a healthy and critical manner. An insidious aspect of altitude sickness is the fact that there are frequent cases of a rapid transition from mild cases to more serious ones. Sometimes, even against a background of complete well-being, without any warning, serious symptoms of altitude sickness can develop and result in sudden loss of consciousness.

As studies have shown, altitude resistance of the organism depends on many factors in the external and internal medium. An unfavourable effect on altitude resistance is produced by overcooling or overheating of the organism immediately before flight and especially during flight, not getting enough sleep, over fatigue, simple stress, flying on an empty stomach or immediately after eating a large meal, an unhealthy state, serious emotional disturbances, residual phenomena following alcoholic intoxication as well as the use of alcohol before flight, excessive smoking, poisoning by exhaust gas, kerosene vapours, gasoline and the products of pyrolysis of lubricants.

Practice has shown that sudden loss of consciousness occurs only in the case of a very rapid climb to an altitude above 5,000 m or in the case of sudden loss of oxygen, at great height. In certain cases, loss of consciousness may occur against a background of apparently perfectly normal behaviour. The pilot may then be unable to detect the moment at which the fainting begins to develop.

Influence of Oxygen Starvation on the Function of the Analysers

Disruption of the activity of the cerebral cortex under conditions of oxygen starvation at high altitudes shows up comparatively early in the functions of the analysers.

The visual analyser is most sensitive to oxygen starvation. It is important to note that it is the principal functions of the visual analyser which are affected, and which are very important to the pilot (for example) for observing and recognizing objects on the ground as well as targets *in the air, reading his flight charts, noting the readings of the instruments, etc. These functions include: colour and contrast sensitivity, colour vision, visual acuity, depth of vision and ability to accommodate.*

Light sensitivity of the eye decreases even at heights of 2,000 -3,000 m, while in some cases even at a height of 1,500 m. At an altitude of 4,500 to 5,000 this decrease becomes significant, particularly in people with insufficient resistance to oxygen starvation as well as under considerable physical stresses. In the case of functional disorders of the cardiovascular activity, light sensitivity deteriorates at lower altitudes and is more pronounced.

The contrast sensitivity of the eye is the ability to detect the smallest differences in brightness between the object and the background; this decreases beginning at 5,000 m. As the oxygen insufficiency becomes more acute, this ability continues to deteriorate and at 7,000 m it falls by 50% on the average.

Colour vision begins to show disturbances at 1,500 m; a further climb makes this disturbance more serious. Beginning at 4,500 my there is deterioration of the ability to detect colour saturation, while at altitudes of 5,000 6,000 m it is difficult to distinguish colour. At these altitudes, white appears as yellowish grey, and black appears as grey. Detection of green and blue deteriorates most sharply. At altitudes of 6,000 m and up, the ability to distinguish blue from green disappears entirely. In order to distinguish other colours from this altitude, it is necessary that they be more saturated.

Visual acuity up to altitudes of 4,500 -5,000 m changes insignificantly if the objects are well lit. However, in the case of low illumination, it deteriorates to a degree which is more serious as the degree of oxygen starvation becomes more acute and the objects are more poorly illuminated. During the daytime, visual acuity deteriorates noticeably beginning at 6,000 m.

The initial phenomena indicating a narrowing of the field of vision are observed at 4,500 m; by 6,000 m this restriction is very markedly apparent.

Depth or spatial vision in some people changes significantly even at 3,000 my while at 5,000 m and up it is seen in everyone. The nature of this disruption depends directly on the degree of oxygen insufficiency and the resistance of the organism to it. The direct cause of the change in depth perception is the weakening of the tone and disruption of equilibrium of the optic muscles, caused by deterioration of the coordinated functions of the central nervous system.

A drop in the ability of the eye to accommodate (characterized by the magnitude of the distance from the eye of the observer to the point of nearest vision) is observed beginning at 5,000 m. Under conditions of oxygen starvation, the time required for normal visual *perception of the surroundings increases. Consequently, some objects (phenomena) which act on the retina of the eye for a short period of time may not be detected.*

A shortage of oxygen also has an unfavourable effect on the retina of the eye itself. Comparatively rapid recovery of the visual ability of the eye during a transition to breathing pure oxygen indicates that under the influence of oxygen starvation the disruptions of the visual analyser have a functional nature, are reversible, and do not cause serious organic damage.

All of the measures that are involved in increasing the altitude resistance of the organism have a positive influence on the recovery of the functions of the visual apparatus. Among the measures that have been especially developed for increasing visual functions, one of the most important is the use of the vitamin A, B and C complex.

The auditory analyser is much less affected by oxygen starvation. Studies indicate that hearing acuity decreases only at altitudes about 5,500 m and may remain depressed for some time after landing. The reason for deterioration of hearing at great heights is the fact that the same thing is affected as in the case of the visual analyser -disruption of the activity of the cerebral cortex.

The functions of the vestibular analyser are disturbed only with a marked degree of oxygen starvation. In the course of experiments with rolling, conducted on special stands, it was established under conditions of pronounced oxygen insufficiency that this disturbance is observed somewhat more frequently than when normal atmospheric air is breathed (at a pressure of 760 mm Hg).

Pain and tactile sensitivity begin to increase at altitudes of 2,000 5,000 m, and decrease with a rise in oxygen insufficiency and increasing altitude per length of time spent at these altitudes. The temperature sensitivity also decreases.

The sense of taste and smell are affected beginning at 4,500 -5,000 m. It should be pointed out that acidified beverages appear to be most pleasant for quenching thirst at high altitudes. With a properly sealed cabin and normal operation of the oxygen equipment, the possibility of development of oxygen starvation is excluded, and so is disruption of the function of the analysers.

Effect of oxygen Starvation on the Respiratory System

The most important effect on the respiratory system is caused not by a rarefaction of atmospheric air, but by a drop in the partial pressure of oxygen in the inspired air.

Under conditions of oxygen insufficiency, there are changes in the external and tissue respiration and the pulmonary gas exchange. The change in respiration under conditions of moderate oxygen starvation are accompanied by adaptive reactions; however, at severe levels of oxygen starvation, reactions of a compensatory nature develop, which in the final analysis may be inadequate, which makes the disturbance of other important functions of the organism more serious.

A fixed characteristic of the reactions of the respiratory system to oxygen insufficiency is the increase in pulmonary ventilation accompanied by a speeding up of the rhythm and an increase in the depth of respiration. A slight increase in pulmonary ventilation in man may already be observed at 1,000 m, while at 2,500 m it is clearly evident. Pulmonary ventilation increases to different degrees in different persons under the same conditions. In some individuals, it may increase by a factor of 2. In general, however, the increase in pulmonary ventilation (when the individual is in a state of rest) depends on the altitude and rate of climb; the greater they are, i.e., the more rapidly the partial pressure of oxygen falls, the more important is the increase in the pulmonary ventilation. It increases particularly sharply in the event of physical stress caused by increased demands on the organism for oxygen. Under conditions of oxygen starvation, with a certain physical stress, pulmonary ventilation increases more significantly than with the same stress under conditions of normal oxygen supply.

With an increase in pulmonary ventilation with altitude, there is a rise in the partial pressure of oxygen in the alveolar air, and consequently the saturation of the blood with oxygen increases. Under these conditions, there is an enormous positive significance of the increase in ventilation of the lungs. However, unnecessary increased ventilation may have a negative influence and cause severe "washing out" of carbon dioxide from the organism, which stimulates the activity of the respiratory centre and also speeds up the saturation of the blood in the lungs with oxygen and its transition from the blood to their tissues of the organism.

When a change is made to breathing oxygen, pulmonary ventilation returns to normal in 1 -2 minutes.

In the case of pronounced oxygen starvation, there is finally a breakdown of respiration. It becomes irregular, frequent, shallow; pulmonary ventilation decreases sharply, which can soon lead to a loss-of consciousness. However, there are frequent cases of loss of consciousness where the increase of pulmonary ventilation and the speeding up of respiration were only slightly evident. Disruption of respiration in the case of severe oxygen starvation develops as a result of inhibition of the respiratory centre in the cerebral cortex.

Hypoxia is different than altitude sickness, though it can be a precursor. Altitude sickness symptoms are nausea, flu-like symptoms and sometimes nose bleeds. Symptoms for hypoxia, on the other hand, can be manifested as euphoria, smiling, giggling, tingling in the fingers or feet, dizziness, disorientation, poor motor control and loss of colour vision. Some people equate it to having had a couple of drinks. However, hypoxia is best known for being insidious—**most people don't realize they are experiencing it until after they begin breathing oxygen-rich air again.**

This is a very dangerous situation or state of mind to be in when about to exit an aircraft.

It takes as little as one minute for a subject to become visibly disabled, although each person reacts and functions differently at low oxygen levels. Factors that can influence hypoxia are the subject's health for instance.

Given all of the above information the added risk of parachuting above 15000ft is significant and considerably a higher risk than below 15000ft.

This risk can be managed with the proper use of supplementary oxygen use. The information however does indicate that any time a parachutists is above 15000ft oxygen should be available.

The opening of the parachute- the effects on the equipment at altitude and the human body.

G forces during canopy deployment.

Parachutes openings whether intentional or not place the parachutists through an opening sequence that requires two primary aspects.

1. The parachutist must be clear of the aircraft and have accelerated to a speed that allows the opening sequence to be completed.
2. The opening sequence will subject the parachutist to a certain amount of +G forces in a vertical axis in a normal opening sequence.

These two parts require time and distance, and even when a parachute is designed packed and maintained correctly the opening sequence cannot be guaranteed the same every time.

For a tandem pair to exit and clear the aircraft, accelerate to a speed that allows the drogue parachute to be deployed and then checked requires at least 5 seconds. This is then followed by a period where the tandem master must assess the drogue is inflated and if not carry out main deployment before the tandem pair accelerates past 15 seconds of leaving the aircraft. In this time the tandem pair will have fallen at maximum 1500ft from the aircraft.

History and statistical information tells us that malfunction rates at some operations are as high as 1 in 600 main deployments and statistically some main parachutes can have 1 in 400 openings recorded as unusually hard or unintentional in some way.

High Altitude Parachute Descents

Every parachute opening includes an amount of opening shock as part of the opening sequence. Opening shock of the parachute equipment is increased with the increase in altitude. This is because the free fall velocity of the pair is greater and therefore the velocity change, between free fall and under canopy configurations, is greater.

Higher altitude leads to more rapid deployment of the parachute canopy, which serves to increase the magnitude of the opening shock and reduce the time over which the opening shock occurs.

During the opening sequence of parachute deployment a normal civilian parachutist experiences a peak of approximately 5G of force. This can be as low as 3-4G and during a hard opening as much as 12G at normal opening heights of 2500-3000ft AMSL.

Tandem parachute harnesses are certified under the same standards however in their particular case the normal opening height is 5500ft AMSL.

To put this in perspective the following are examples of other G force exposures.

- Standing on the Earth at sea level, where g force = 1 g
- A ride in the Vomit Comet , with g force = 0 g
- Standing at its equator on the Moon, with g force = 0.1654 g
- The gyro rotors in Gravity Probe B and the free-floating proof masses in the TRIAD I navigation satellite, with g force equal to 0 g
- Saturn V moon rocket just after launch, g force = 1.14 g
- Bugatti Veyron from 0 to 100 km/h in 2.4 s, has g force = 1.18 g
- High-g roller coasters have g forces ranging from 3.5–6.3 g
- Top Fuel drag racing world record of 4.4 s over 1/4 mile, g force = 4.2 g
- Space Shuttle, maximum during launch and re-entry, g force =3 g
- Luge, maximum expected at the Whistler Sliding Centre, g force equal to 5.2 g
- Formula One car, maximum under heavy braking, g forces = 5 g
- Apollo 16 on re-entry, g forces = 7.19 g
- Standard, full aerobatics certified glider , g forces = +7/-5 g
- Death, g force can be greater than 50 g
- Max. turn in an aerobatic plane or fighter jet, g forces ranging from 9–12 g
- Maximum g force for human on a rocket sled = 46.2 g
- Sprint missile, g forces = 100 g
- Brief human exposure survived in crash has g forces > 100 g
- Shock capability of mechanical wrist watches g forces > 5,000 g
- Rating of electronics built into military artillery shells, g forces equal to15,500 g

Parachutes are certified under a variety of standards that vary and there is no “one standard” across the board. It is accepted however that the most common standard being the TSO23 and that under this standard 8G is the maximum allowable loading that is “certifiable” under this testing process.

Using a known test sequence and reports independently completed by the US military we know the actual forces that have been recorded during test parachute openings in controlled conditions.

By using these figures it is possible to determine approximate loadings on a tandem parachute harness in normal operations, certified limits and under recorded hard opening conditions.

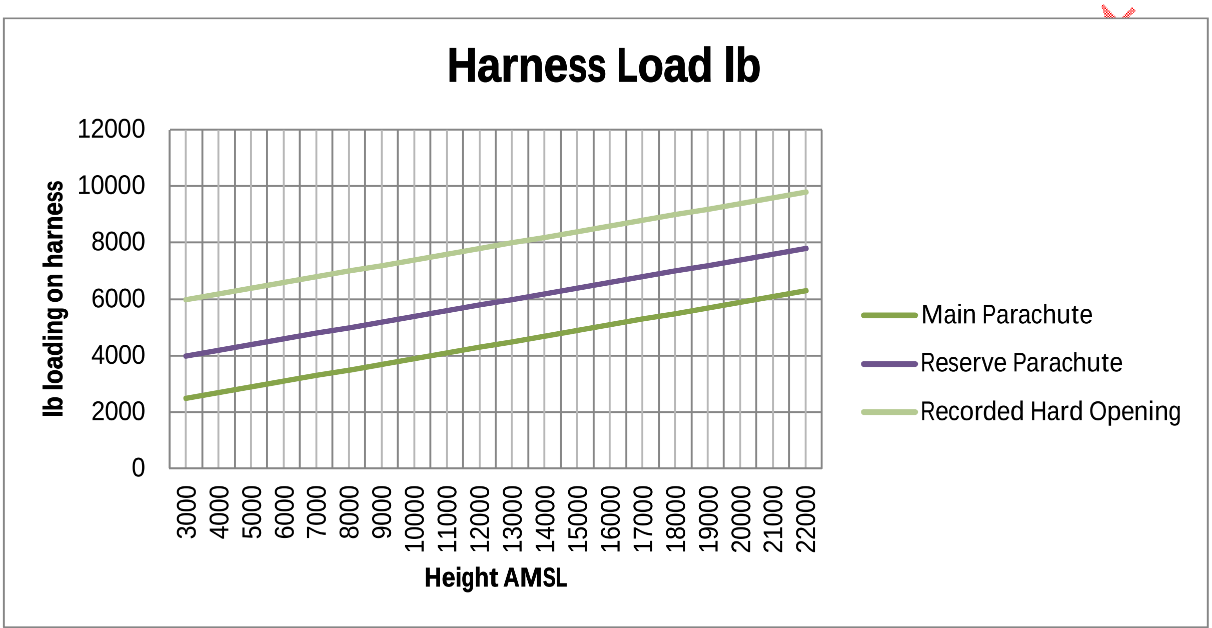

Fig 1

Parachute harnesses are typically manufactured of Mil spec Type VII webbing certified to 6000lb. Using the max allowable load of 500lb under the major tandem harness container manufacturers the loads can be seen in both fig 1 and fig 2 regarding lb and G forces.

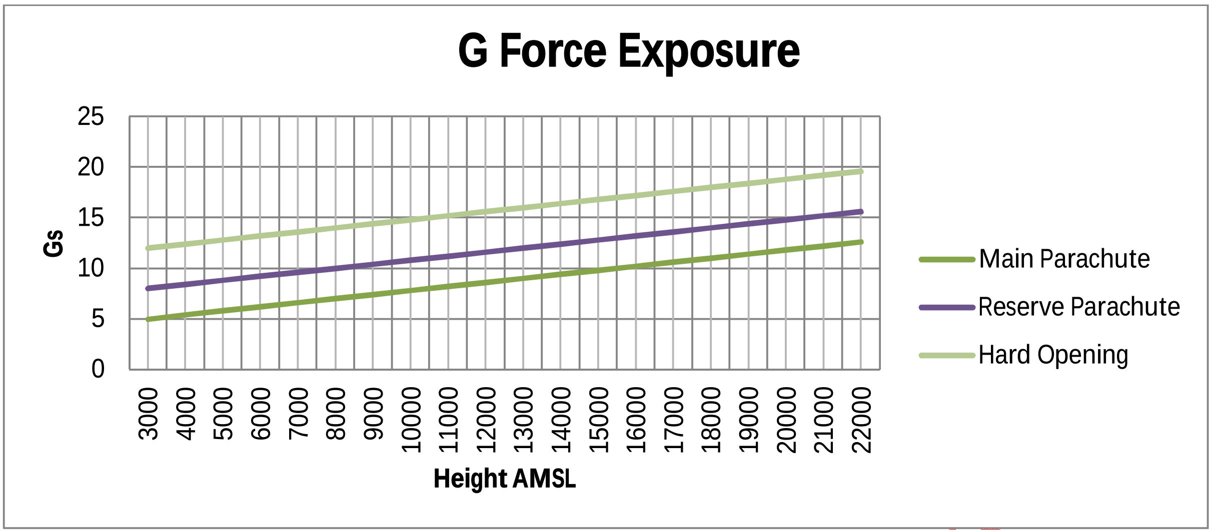

Fig 2

Using these figures we can estimate the loadings in both harness lb compared to the 6000lb limit, the G forces compared to the normal 4-5 G for a main deployment and 8 G for the certified tested limit. We can also estimate at what height the 12 G estimated limit will be reached above which the likelihood of injury and equipment damage will occur. We know from NASA actual test results that eyes down G force injury occurs at 16 G. this is a critical factor. Excess of this number is almost certain of injury.

AMSL	Peak G during normal Parachute Opening	lb loading on harness		Certified Limits	lb loading on harness		Actual testing of a hard opening	lb loading on harness		Exit weight
3000	**4.2**	2100		**7.2**	3600		**11.2**	5600		500
4000	**4.6**	2300		**7.6**	3800		**11.6**	5800		500
5000	**5**	2500		**8**	4000		**12**	6000		500
6000	**5.4**	2700		**8.4**	4200		**12.4**	6200		500
7000	**5.8**	2900		**8.8**	4400		**12.8**	6400		500
8000	**6.2**	3100		**9.2**	4600		**13.2**	6600		500
9000	**6.6**	3300		**9.6**	4800		**13.6**	6800		500
10000	**7**	3500		**10**	5000		**14**	7000		500
11000	**7.4**	3700		**10.4**	5200		**14.4**	7200		500
12000	**7.8**	3900		**10.8**	5400		**14.8**	7400		500
13000	**8.2**	4100		**11.2**	5600		**15.2**	7600		500
14000	**8.6**	4300		**11.6**	5800		**15.6**	7800		500

15000	**9**	4500		**12**	6000		**16**	**8000**		500
16000	**9.4**	4700		**12.4**	6200		**16.4**	8200		500
17000	**9.8**	4900		**12.8**	6400		**16.8**	8400		500
18000	**10.2**	5100		**13.2**	6600		**17.2**	8600		500
19000	**10.6**	5300		**13.6**	6800		**17.6**	8800		500
20000	**11**	5500		**14**	7000		**18**	9000		500
21000	**11.4**	5700		**14.4**	7200		**18.4**	9200		500
22000	**11.8**	5900		**14.8**	7400		**18.8**	9400		500
23000	**12.2**	6100		**15.2**	7600		**19.2**	9600		500

Given that we know the tandem pair must fall for 15 seconds before these G forces can be reached, the maximum height listed here can be raised by 1500ft above these heights to allow for the tandem pair to accelerate to a speed where these figures can be reached.

As can be seen by the above figures under normal operations and limitations, the following will likely be the result of any high altitude deployments.

1. Harness load limitations of 6000lb will likely to be exceeded at 15000ft AMSL and the parachutist will be exposed to about 12G under a normal reserve parachute opening if the tandem pair exits higher than 16500ft AMSL and has either an intentional or unintentional reserve deployment.
2. Harness certified load limitations of 6000lb will likely be exceeded at 15000ft AMSL and the parachutist will be exposed to 16G under any unusual canopy deployment intentional or unintentional above 15000ft AMSL if the tandem pair has been in free fall or drogue fall longer than 15 seconds. This is almost certain to result in injury.

There are a number of reported hard openings and numerous reported equipment failures from hard openings world-wide, this would suggest that these figures are fairly accurate.

Reported injuries from hard openings on parachutist from medical studies run at 5% of all parachute injuries including fatalities from hard openings.

This would support the information that suggests that a loading of in excess of 12 G would be uncomfortable but not likely to damage the equipment or parachutist more than minor injury. It might however weaken the equipment as a vehicle crash could weaken a seat belt in a car. This loading would be similar to a car accident that caused bruising from the seat belt on impact.

The effects of G forces on the parachutist during deployment

Parachute design has changed dramatically over the past ten years. Main parachutes today are designed to open in a much more controlled manor than was previously possible in years gone by.

Main parachutes do not have a "standard" as reserve parachutes do. As such we see large variations in manufacturer's ideas and the "market forces" dictating the direction of canopy design. What may be acceptable to one Operator may well be unacceptable to another in main parachute performance.

The opening characteristics of the main parachute may differ considerably from the reserve parachute. While the reserve parachute will open within 3 seconds and expose the parachute pair to much higher G forces, these will be for a much shorter period of time than a normal opening on the main parachute. The main parachute will expose the parachutist to a lower G force for a longer period of time, perhaps 4-6 seconds.

G Forces during the opening sequence on either the main parachute or during a reserve parachute deployment can be reduced along with the loadings on the equipment by the use of larger canopies and drogue parachutes. This is common practice in the military for instance. In civilian commercial parachuting however the trend has been for the practice to be on smaller faster parachutes rather than larger slower parachutes. While the military may use a reserve and main parachute of 425 sq ft and even larger to compensate for the larger loads and higher altitudes that the equipment will be exposed to, commercial tandem parachutes commonly use reserve parachutes of 360 sq ft and main parachutes in the tandem market are now commonly only 330 sq ft and are available as small as 280 sq ft. Canopy manufactures will manufacture tandem canopies to any dimensions the customer requests.

The history of tandem jumping world-wide shows that pilot error during a malfunction, out of sequence deployment or unusual situation is the number one cause of fatalities in tandem jumping.

The G tolerance the human body has been well studied and documented in many sports. Aviation is only one area that has highlighted concerns with G forces, motor sport has also in recent years highlighted concerns with G forces and the effects on track design has been significant as just one area where these studies have made significant improvements.

The effects G forces have on the tandem pilot therefore must be considered. The critical time for any skydive is at main parachute deployment time whether intentional or not, and the decision as to what procedure is next carried out is critical to the safe continuation of any skydive and the survival of both participants. This single decision is the number one cause of tandem fatalities world-wide.

Here we consider the effects of G forces during parachute deployment in relation to the tandem masters ability to carry out these decisions at the time of parachute deployment. To make this decision in oxygen depleted environment would complicate the decision making process and endanger both participants.

G- TOLERANCE

Centrifuge and Flying studies have identified man's tolerance to +Gz with reasonable accuracy. Figure 3 is a +Gz v. Time graph demonstrating the tolerance to +Gz of relaxed subjects not using any G-protection device or manoeuvre.

The area above and to the right of the solid black curve represents the +Gz and Time at which unconsciousness (on average) occurs. The area between this curve and the grey curve is the region of visual disturbances (greyout and blackout) without loss of consciousness. Below and to the left of the grey curve is the +Gz/Time zone where no visual symptoms or G-LOC occur in the average, unprotected person.

The line 'C' on figure 3 represents a gradual onset of +Gz at a rate of around 0.5G per second and shows that visual symptoms are likely after about 5 seconds and Loss of Consciousness about 1 second later at +4Gz. Line D shows a slower rate of +Gz onset, in this case visual symptoms will occur after 16 seconds (+4Gz) and G-LOC will intervene after 22 seconds when the acceleration will be +5Gz. Rapid onset of sustained +Gz, as shown in line B will result in G-LOC after about 4 seconds without any warning visual symptoms. However, very rapid onset +Gz that is not sustained at a high level, line A, may well result in no visual disturbances or G-LOC. This last feature is what saves many of our unlimited aerobatic pilots from suffering G-LOC more often, although they pull substantial G they do so for only very short periods

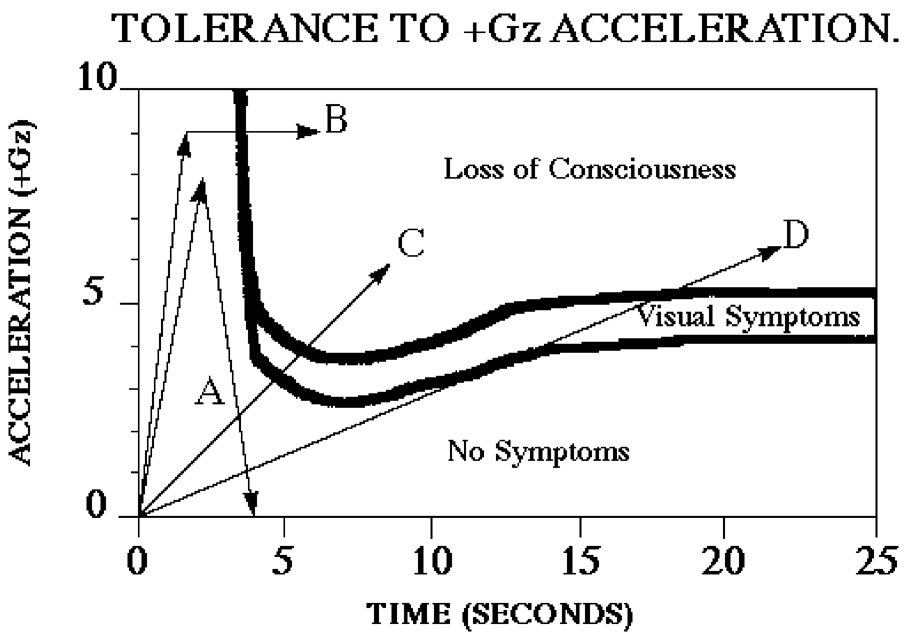

Fig 3

Although various studies provide slightly different figures for G-LOC most show that it tends to occur at around +4.5Gz in the unprotected individual, but may occur at anywhere between +2Gz and +6.5Gz. Aircrew have suffered G-LOC at +2Gz, which is the G-loading during a

steep, balanced, 60 degree angle of bank, turn. It is also important to note that although G-LOC is often preceded by visual symptoms this is not always the case.
The duration of a period of G-LOC also varies, after the G returns to +1 Gz, but usually the period of complete incapacitation lasts around 15 seconds and is followed by another 15, or so, seconds of relative incapacitation. Periods of up to 3 minutes incapacitation have been observed.
The loss of memory that often occurs during G-LOC is particularly concerning as it leaves the pilot totally unaware that they have been unconscious and may provide them with a false perception of how well they can cope with G.

There are a number of key points to this information above.

1. **That higher G forces can be sustained but only for periods of less than 4 seconds.**
2. **That the unprotected individual can be effected by G-LOC when exposed to forces from as low as +2Gz for longer than 4 seconds.**

There are also a number of significant concerns within the above information.

1. **That any people that are affected are likely to involve memory loss.**
2. **That affected persons may also be affected by vision issues.**
3. **Those symptoms may include unconsciousness and may not include any pre warning signs.**
4. **That affected persons incapacitation may last upwards of three minutes.**
5. **That these symptoms have been reported in parachuting incidents and malfunctions during past investigations at normal altitudes without even considering the effects of high altitude.**
6. **That the information** could be **just as relevant to parachute deployment or malfunction training as it is to other forms of aviation or motorsport.**

Reserve Parachute Deployment

As previously stated, most reserve parachutes will open within 3 seconds exposing the parachute pair to a relatively high G force for a relatively low period of time. While this may have damaging effects on the pilot and passenger the reserve is made for use in an emergency situation and as such this chance or risk must be accepted to a certain level. There is a level however where injuries are reported from hard openings, this does appear to be above the 12G level.

Any G-LOC affected parachutists from reserve deployment are probably difficult to verify for a number of reasons.

1. That the opening shock is below the 3 seconds so unlikely to be an issue on canopy deployment from the reserve alone.

2. That the opening is generally at a lower altitude.
3. That the deployment is generally after a malfunctioning main parachute.
4. That any G force is likely to be in the higher end with no pre warning and any G-LOC effected skydiver will likely have no memory of the event.

Main Parachutes

Main parachutes today are being designed to open much slower than ones of yesterday, the demand for slower more consistent opening parachutes has resulted in main parachutes with varied opening characteristics. While some open within a relatively short period on within 3-4 seconds there is a definite market for a slower more comfortable opening parachute and some now are opening well into the 5-6 second bracket as a design/market requirement.

What can be seen by the information above is that in a normal main deployment it is likely with a main parachute at any altitude that take more than 4 seconds to open, the parachutist could be exposed to more than 3 G and perhaps as much as 5 G.

With the normal opening sequence taking longer the time before the Tandem Master in this case will mean the pair will be exposed to these G forces much longer before making a decision as to whether to carry out their emergency procedures. While in the past we would expect the parachutist to be exposed to the opening shock for 3 seconds and then make a visual decision and then a mental decision under a peak G of 8 for a short period under 2 seconds and then sustained lower G of 3- 4 for perhaps 3-4 seconds now we are facing the possibility of a different situation.

Main canopies now can take 6 seconds to open and these can be lower sustained G forces of 2-4 G, at this time the jumper must make a visual and then a mental decision as to what action to take next. If at that stage the parachute enters any sort of malfunction or spin the G forces will again be increased and the possibility of G-LOC increases significantly.

If the parachute malfunctions or spins then the spike in G force will significantly increase at the point during the opening.

Given the study in G-LOC it is reasonable to expect that with the change in parachute design that parachutists could be affected by G-LOC during normal parachute deployment when using a main parachute that either malfunctions for longer than 4 seconds, or takes longer than 4 seconds to open at any altitude.

Chance of the parachutist knowing they have been affected is however unlikely as the resulting loss of memory that result would prevent the tracking of the issue unless an accident occurs and is investigated as a result.

Reports.

There are various reports of parachutist having no memory of periods of a malfunction or deployment over the past few years.

This has in the past been put down to a variety of causes and as such there has been a record of fatalities that are yet unexplained that could be the result of G-LOC.

The lack of memory that results from this makes reporting and tracking this difficult.

Reviewing this information and the recent trend of main parachute design where the deployment times have been increased to over 4 seconds as the normal, this may well have resulted in placing the parachutist into a dangerous situation or G-LOC affected state at a critical time in a normal parachute jump.

In 1997 there was a parachute accident at the south pole in which three skydivers were fatally injured. There are some very good lessons that can be learnt from this jump. One interesting similarity was that the exit altitude was 17000ft AMSL and there was no use of oxygen by the three skydivers that were killed. One of the three that survived, a tandem master, used a portable oxygen system and mask similar to the systems in use in New Zealand has this to say.

The South Pole is one of the highest, driest and coldest places on earth. Elevation is approximately 9,300 feet above sea level. So their jump from 8,000 feet above ground level was actually about 17,000 feet above sea level. And due to the density of the cold air, terminal velocity would be 36 per cent faster than normal, making their fall rate about 163 mph. Calculating for air density, their altitude was equivalent to about 22,000 feet above sea level.

Looking Back

What happened? What went so wrong? How could three experienced skydivers not pull? Were they disoriented by their lack of depth perception in the monotonous, white landscape? Were they disabled by the extreme temperatures? When investigators inspected all the equipment, they found that the only item that had not functioned in the extreme cold was the video camera. It froze and ceased working as soon as it hit the wind in the door of the plane.

After the jump, he also said that upon deploying his main, "We could now feel the lack of oxygen and felt very tired at this moment, but still we were very happy." He also said that the toggle pressure was hard: "Both of us had to pull down the toggles to flare."

During freefall, Kearns recalls one dangerous symptom of hypoxia: "I looked at my altimeter three or four times, but it didn't mean anything to me."

Hypoxia is alleviated very quickly as oxygen enters the system. Both Kearns and one of the others attempted to deploy, but terribly low. Most likely, they began to recover quickly from *the hypoxia once they were at the lower altitude. Unfortunately, the ground was 9,300 feet above sea level, and the air was still somewhat thin.*

Statistics overseas show an alarming trend. A quick tally of serious accident and fatality trends indicates that of the last 50 serious accidents in the USA 54% we fatal, 8% involved a collision with the parachute aircraft on exit and 50% of these collisions were fatal. This trend has been an increasing trend in recent years as the introduction of new disciplines in skydiving has been introduced and new faster aircraft have been introduced into the industry worldwide.

The equipment used for parachutists for the supply of oxygen in the aircraft.

Primarily oxygen is supplied to parachutists in the aircraft through a facemask and a continuous feed system.

There is a moving trend towards pulmonary automatic oxygen systems where the oxygen is supplied only on demand from the parachutist. These however are also supplied generally by the use of a facemask or this type of semi open delivery to each individual.

Oxygen Masks with on-board stationary oxygen systems

A mask of this type must fit very closely to the face; otherwise outside air will be drawn in. This means that every pilot must carefully put on the mask and strap it to his face.

After each use, the mask must be carefully wiped and dried.

Masks of both the open and semi-open type have openings through which the space beneath the mask communicates with the atmosphere. This means that atmospheric air is drawn in together with pure oxygen when the user of the mask draws a breath. As a result, the oxygen mixes with the air which the individual breathes. The oxygen content in this mixture depends on the amount of oxygen supplied beneath the mask and the depth of respiration. When the flight altitude remains the same, the amount of oxygen also remains fixed; the latter is sufficient for respiration in a state of relative physical rest. However, under conditions of physical and neuro-emotional stress, the depth of respiration (pulmonary ventilation) increases significantly , *so* that the volume of the air drawn in beneath the mask increases, and the gas mixture contains less oxygen. Finally, the person begins to suffer from oxygen insufficiency, which may lead to a decrease in working ability. This is the principal short coming of these devices.

Another shortcoming of these devices is the uneconomic consumption of oxygen; oxygen is supplied continuously, but used only during inspiration; it escapes freely into the atmosphere during expiration. Hence, more than 50% of the oxygen is wasted. Oxygen devices with continuous oxygen feed have a number of advantages over devices of other types. The most important of them are the following :

1. -low resistance to respiration;
2. -convenience of use, simplicity of design, small size of the device, mask and hose;
3. -insignificant variation in the composition of the inspired mixture with relatively loose attachment of the mask to the face.

Shortcomings of these masks and delivery systems are as follows:

1. -uneconomic use of oxygen because it is supplied during expiration and the pauses between inspiration and expiration;
2. -deterioration of oxygen supply ***to*** the organism during physical or neuro-emotional stress.

Conclusions

Accent.

To reduce the risk of hypoxia being a factor during the descent or during any inflight decision process during an inflight emergency.

1. Oxygen is required for all parachute descents when the aircraft is ascending above 15000ft AMSL.
2. The system must be turned on and parachutist must continuously be breathing oxygen from at least 8000ft AMSL.
3. The faster the aircraft can climb the earlier the oxygen should begin being used.
4. If the aircraft is going to be above 8000ft AMSL for longer than 30 min oxygen should be used by all people on board.

Simple face masks or open hoses connected to either continuous supply or on demand oxygen delivery systems are not effective above 15000ft.

5. At any time the aircraft is above 15000ft AMSL the parachutists should have a properly fitted (sealed) mask with oxygen supply.

There is a time between when the parachutist must remove the oxygen and the exit sequence must be initiated, this time could be as varied from as little as a few seconds to as much as few minutes.

Should any aircraft emergency happen during the exiting of any parachuting the demand for oxygen on the jumpmaster or loadmaster is imperative.

6. At any time the aircraft is above 15000ft AMSL the person designated as load master should not disconnect from the oxygen supply until all other parachutists are clear of the aircraft.

Descent

The parachutist or tandem rider should not at any stage be put in a situation that in a normal jump the known limits or conditions are likely to injure or knowingly endanger either themselves or their passengers.

Whenever the free fall is longer than 15 seconds the parachutist shall not be exposed to an opening shock that would be more than what can be expected on a normal jump with an abnormal opening or an abnormal jump with a normal opening.

1. Should the main or reserve parachute open intentionally or unintentionally after 15 seconds of free fall the calculated opening shock should not exceed 12G for a normal opening.
2. The calculated opening shock for the main or reserve parachute for an unusual opening should never exceed 16G due to the likelihood of injury.
3. That the loadings on the harness should under a high altitude opening not exceed the maximum loads of the equipment limitations. (6000lb)

That the tandem master and passenger recognise the significant increase in risk when parachuting from above 15000ft AMSL.

That the operators recognise their responsibilities under the HSE Act and their procedures reflect the increase I risk and responsibilities in carrying out parachute descents above 15000ft AMSL.

4. That operators ensure that tandem masters, tandem riders and solo parachutists be monitored in accordance with Section 10 of the HSE Act whenever parachute descents are made above 15000ft AMSL.

Canopy selection.

The effects of G forces on parachutists are probably wider spread than is possibly known within the industry. The change in canopy design in recent years has quite possibly pushed this issue closer to becoming a real issue in the industry than ever thought before. Just as the issue has been addressed in other industries that never thought it would have any effect on their design, skydiving will have a similar result if not monitored.

During any emergency or malfunction this issue is likely to be highlighted first. With the added complication of –G in free fall emergencies also a possibility the issue is a subject for another study.

To be close enough to G-LOC and to add the complication of being in a low oxygenated atmosphere or high enough that the possibility that a person could pass out is a hazard that needs close monitoring. While a certified skydiver may have an understanding of the risks and a method of minimising the risks through training and certification, a paying passenger has very little possibility. The qualified skydiver also has by the nature of many previous jumps also been through a self-testing procedure that should have removed any totally G intolerant candidates.

The effects of canopy openings and G-LOC are probably affecting the tandem riders more than the tandem masters as they are untrained and unqualified. However to reduce the possibility of putting the tandem master into a dangerous situation at a very dangerous time tandem canopies should be selected that have opening characteristics that do not enter the possibility of the passenger or the tandem master being effected by G-LOC.

Once again the requirements of the Health and Safety Act 1992 need to be highlighted.

1. Openings should be completed within 4 seconds and turns and manoeuvres should be restricted to both under 3 seconds and under 2 G.
2. Ensure that all main parachutes used for parachute descents comply with Section 18A of the HSE Act in that it is designed and made so that it is safe for its intended use.

Canopies that have hard openings should be reported, canopies that are taking opening longer than 5 seconds should be retired or not used in tandem jumping.

3. That operators should report any hard openings, long openings and restrict weight limits to ensure that the limitations of the equipment are not exceeded.

Health and Safety, Civil Aviation Rules

Irrespective of the Civil Aviation Rules, the NZPIA or any other requirements, the Parachute Operator and the Tandem Master has a responsibility under HSE legislation to provide a safe working environment to both employees and persons that are at the place of work.

The Civil Aviation Rules require the aircraft operator and the individual parachutists to comply with specific prescriptive rules that in some instances are more restrictive that the conclusions in this report. As detailed in the introduction it is not the author’s intention to comment on the safety effectiveness of these rules.

What is the safest maximum height for tandem descents?

Given all of the information reviewed in this study the maximum exit height for tandem parachute descents without bailout oxygen?

High Altitude Parachute Descents

With current civilian equipment used in tandem jumping in the New Zealand adventure tourism industry – the tandem pair or parachutist must pass 15000ft AMSL within 15seconds of free fall or drogue fall unless bailout oxygen is used for the entire descent until the parachutist or tandem pair is below 10000ft AMSL.

It is also given the maximum loading on civilian equipment of 6000lb that this load will be exceeded with a 500lb load at any height above 15000ft AMSL where the reserve parachute is deployed after 15 seconds of free fall.

It is almost certain that any exit height above 16500ft AMSL it will not be possible meet this requirement without the use of a bailout oxygen system and or non-civilian tandem equipment.

If there is any canopy deployment after 15 seconds of free fall it is almost certain to result in injury or fatality as a result of either equipment failure, human factors and incapacitation or environmental factors related to altitude should the parachutist or tandem pair exit above 16500ft AMSL.

The information provided here is provided to help all meet your obligations as follows:

1. That the equipment used in civilian parachuting should not be exposed to loading and conditions over and above what it would be expected to endure on a normal descent.
2. That the Tandem Master should not be exposed to an unacceptable risk in conditions that significantly increase the risk of injury or death in carrying out their duties and responsibilities.
3. That the Tandem rider should not be exposed to an unacceptable risk in conditions significantly increase the risk of injury or death in carrying out a tandem descent.
4. That the Parachute Operator should be made aware of their responsibilities under the Health and Safety Act 1992 in providing a safe workplace for the tandem masters and the tandem riders in carrying out any tandem descents.
5. That tandem masters should be made aware of their responsibilities under the Health and Safety Act 1992 in providing a safe workplace for the tandem riders in carrying out any tandem descents.

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