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BASEic Sport Parachuting: "We'll Jump Off That Bridge When We Come To It"

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Abstract

This is an introduction to the art and science of the new sport of BASE jumping – sky diving and parachuting from fixed objects rather than from aircraft. It covers the history and technical advances with emphasis on the period from the beginning of modern BASE jumping in 1978 through the current popularization and public awareness of the sport. BASE jumping, as the latest step in the progress toward natural human flight, is explored in its advancement away from dependence on aircraft toward the purer, more natural means of using fixed objects for altitude.

Origins

Using parachutes to descend from fixed objects is a pastime that evidence suggests has been practiced, though infrequently, for at least the last 900 years. [1] Yet, in just the past eight years, probably more jumps of that kind have been made than in all the previous years combined. BASE jumping is the modern appellation for the popularized version of the sport of jumping off of fixed objects and deploying a parachute for a safe landing. Unlike most leaps that were practiced from the twelfth century into the eighteenth century, today's BASE jumps emphasize launching without a previously inflated canopy. So, nearly anything that stands immobile and vertical or overhung could be considered jumpable.

From the late 1700's through the nineteenth century, the advent of manned balloons drew the development of parachuting largely away from fixed objects to jumping from aircraft. It was not until the twentieth century that fixed-object jumping slowly began to pick up momentum again as an extension of sport parachuting from aircraft. The early 1900's saw the odd bridge jump and one stuntman's static line jump from the Statue of Liberty. The military's closest involvement to fixed-object jumping became represented by its parachute training towers, built shortly before World War II and still maintained. Otherwise, parachuting from fixed objects has had only civilian and sport applications.

By the 1960's, sport parachuting from aircraft had developed to the point that experienced sky divers began to more seriously consider trying their wings from non-flying objects. At the increased frequency of about one per year, there were incidents of people making calculated leaps from cliffs in the Italian Dolomites, El Capitan in Yosemite National Park, oil well derricks, or still the odd bridge. Unfortunately, most of these early leaps were poorly recorded, so little is known of them except that they were all done with contemporary round canopies and with varying degrees of success.

Finally, in the next decade, BASE jumping began blossoming into a sport in its own right. In 1970, a parachutist, using a standard 28-foot military surplus round canopy, successfully jumped from the 1,053-foot-high Royal Gorge Bridge in Colorado. Then, the following two years, another sky diver made three more jumps from El Capitan, this time by skiing off with a triangular-shaped Thunderbow canopy. The jumper was an expert skiier novice sky diver who would, in 1976, repeat the stunt for a movie, but with a round-style Para-commander canopy and from Mt. Asgard on Baffin Island. Though newer, better performing square-style parachutes were being developed at the time, in 1975, a highly-publicized jump was made from the 110-story New York World Trade Center by a jumper still using a round canopy. But it was really the El Capitan ski jumps that proved to be an important catalyst in the popularization of fixed-object jumping a few years later.

By 1977, a small group of very experienced aircraft sky divers (some of whom were also expert hang glider pilots, and all pioneers) had realized that with the new, modern, high-glide-ratio square canopies, the overhanging El Capitan now could be repeatedly jumped with consistency in reaching the meadow landing area instead of landing in the rocks or trees directly below. These jumpers made plans to jump El Capitan the following year. The thought was finally right for the concept of powerless self-flight to branch off from aircraft launches and return to its pure roots of using objects for altitude, as had been done until the eighteenth century and the advent of manned balloons; the fuel shortage was still fresh in people's minds, the prices of aircraft rides to altitude for sky dives was climbing, and jumping from fixed objects finally appeared reliable, ecological, expandable, and accessible to anyone.

Popularization

On August 18, 1978, after putting a year of thoughtful research into the concept, a group of four expert sky divers made the first modern leaps from El Capitan, and popular BASE jumping was born. The jumpers used their regular aircraft sky diving gear: a state-of-the-art piggyback dual container system with the round reserve on the top and the square main below, tape-well or three-ring riser quick-releases, leg straps with B-12 snaps or thread-through closures, and standard 36-inch pocket-stowed pull-out pilot chutes. The plan was for each jumper to run and dive off singly, track for eight to twelve seconds, deploy, and fly to land in one of the large meadows one-half mile away. The launch point is a 30-degree downward slope of weathered granite about 12 feet long that allows a running launch off the 7,040-foot above sea level cliff; an average free fall delay of 10 seconds would place the jumper approximately 1,053 feet lower; full opening would be about two seconds later and 200 feet lower, leaving the jumper approximately 2,000 vertical feet to the 3,980-foot asl landing area and about 1,700 feet to the talus directly below.

The first jumper exited according to plan, but not quite according to the actual, but unforseen, demands of the site. The momentum from his running and diving exit continued to pitch him over in a ll flight, or by removing it entirely. Not ite a year later, this slider-down pack method d been tried, proven, and accepted as the imary equipment alteration to ensure swift ployments of square canopies for free fall alys of up to four seconds.

In 1980, some direct experimentation was done th airspeed on exit. Fixed-object jumpers eorized that a build-up of momentum could aid th stability on launch and better clearance from e object, much as the acceleration of previous i jumps had carried the jumper off the edge and ay in a condition more closely related to miliar aircraft sky diving. One jumper tested a unch over the railing of a 450-foot-high bridge om the bed of a truck travelling at 70 miles per ur. He exited less than halfway across the idge so that the forward throw of the launch uld carry him to the deepest part of the ravine r deployment. The jumper used a pilot-chute-ployed round canopy freely packed in a piggyback ntainer, which he insisted on tacking closed with ly a strand of home sewing thread. The canopy me out 45 degrees to horizontal and opened at an impressive altitude as the jumper, who had ipped on push-off, was head-down and terribly stable during deployment to the point where a oke canister he was wearing on his foot burned rt of the canopy during extraction. Some months ter, better stability data was obtained at El apitan during the permitted jumping season: servation of running launches, standing launches, nd two exits made riding skateboards off revealed at extra momentum magnified, but did not improve, e quality of stability on exit, but extra omentum always increased the distance that could e attained from the object.

In the latter half of 1980, the cliff jumpers' epertoire expanded to include television and radio ntenna towers, the second highest bridge in the nited States — West Virginia's New River Gorge ridge — and two new major cliff sites at opposite nds of the altitude spectrum — Norway's mile-high rollveggen, and Arizona's 580-foot-high Canyon de helly. The same equipment was still being used, ut technique was being perfected. All of these ites, plus others, afforded jumpers places to test nd expand the limits of the new sport with regards o multiple-jumper launches, exit techniques, anopy and equipment specifications, static line ersus free fall requirements, and effects of wind onditions. Generally, fixed-object jumping emained similar to aircraft sky diving in nearly ll respects except for the still-air launch, he on-heading opening requirement, and the tricter time constraints. However, a multiple - umper exit, also called relative work, presented a ew set of challenges.

At El Capitan, it was quickly discovered that ircraft sky diving techniques of simply holding nto one another to exit together as a unit did not ork. The formation would immediately fall apart pon launch due to the differences in acceleration f the jumpers. Even when just one jumper would xit right behind, and within reach of, another, hough there was less than one-half second ifference in launch times, a 10-foot separation ould result. Ideally, the jumpers would exit ide-by-side, as they could at other sites, and hen accelerate together at the same rate, but El apitan has two unique launch point characteristics hat need to be coped with: its slope, and its ildly pointed shape. In one instance these were iscovered to be potential assets when it came to relative work: a wedge-shaped formation, with one jumper in front and one off to each side and behind would place each of the three jumpers the same distance from the edge on the wedge-shaped launch point; therefore, on exit they would all accelerate similarly with a better chance of staying stable and linked, and staying stable is the key to doing relative work from fixed objects. On the other hand, if the aforementioned wedge formation were to be changed to a diamond by adding a closing jumper behind, that person would probably find himself pulled head-down and over off the launch point as the jumpers ahead of him accelerated away, and he would quickly lose his grips. However, two-person launches, one directly behind the other, can be done if the front person jumps up on exit and the rear person jumps out to negate the acceleration difference. Possibly, this could also be a practical solution to the diamond formation dilemma. Other than side-by-side formations, true relative work has yet to be perfected in fixed-object jumping.

The first jumps from the 580-foot-high wall at Canyon de Chelly in Arizona exhibit the striking progression of the sport of fixed-object jumping when compared to later jumps made at the same site. On October 3, 1980, the standard pin-closed sky diving piggyback main and reserve set-up with a normal sized pilot chute was still being used for all fixed-object jumping. On that day, the first four jumps were made from Canyon de Chelly using static-lined 23-foot Piglet round canopies on singl exits. Square canopies were not used due to insufficient wall clearance in case of an off-heading opening; free fall was not considered because of insufficient margin for reserve altitude in case of an emergency; and releasing a malfunctioned main canopy before deploying the reserve was not considered a viable alternative. Three-second free fall delays were taken, openings were just above halfway down, and time under canopy was just over 15 seconds. In contrast, almost two years later, and at a different site, lighter, F-11 26-foot R4-2 round canopies with large pilot chutes had been free fallen for three seconds from a 400-foot cliff over water, and openings were found to b just about halfway down. Armed with the new information and equipment, by 1983 the Canyon de Chelly site was being visited consistently by jumpers doing two-person exits, one behind the other, taking two- and four-second respective free fall delays; even one modified three-person exit was done with the third jumper launching as soon as the first person's canopy began to open.

The very end of 1980 marked the end of the pioneering era of fixed-object jumping and the beginning of a continuing era of development. The legwork had been completed for the first sport building jumps to be history in less than one mont and periodic media coverage was being given to fixed-object jumping as a spectacular thrillseekin activity, but far-sighted jumpers could see their new pastime becoming an accepted sport before the turn of the century. Already, improved equipment was being designed and tested, and there were abou 500 fixed-object jumpers worldwide.

Development

The United States BASE Association

In January of 1981, the acronym BASE was coine to denote fixed-object jumping by the four possibl categories of jumpable objects: Building, Antenna tower, Span, and Earth. That same month, the first sport building jumps were done, and with those, four jumpers had completed jumps from each object category and were designated the first four sequential BASE Jumper numbers. Concurrently, the United States BASE Association was founded by Carl Boenish and dedicated to the safety, advancement, and positive public image of BASE jumpers and BASE jumping throughout the world. BASE jumping was designated a sport, not a stunt, and the publication, *BASE Magazine*, was initiated to share technical, research, and event information, and observations and inspiration with anyone interested in the concept of BASE jumping. The Association became a multimedia information and data center supplying both the jumpers and the public with whom it interfaces.

Generally, the USBA is made up of hardy individualists who share a common interest in the development of the idea of self flight and the quality experiences it offers; they represent a complete cross section of society with an emphasis on freedom, self-direction, and self-reliance. No one is ever encouraged to take up BASE jumping. If a person has the proper inherent mental make-up and is so-inclined, he tends to seek it out, usually as a more individual and natural progression from aircraft sky diving. Even within the BASE community, not everyone should climb up and around the edges of particular objects, and it frequently takes much more courage, discretion, and character for a jumper to decide not to participate in a jump than to jump on the basis of being there, much as an addiction would encourage. Though each jumper has individual motives and reaps unique benefits from participating in BASE jumping, they all generously share their enthusiasm and understanding with anyone who expresses a curiousity. Such jumper-spectator interaction also helps to both educate and inspire the general public, whose members have always reacted positively to BASE jumping in general and never with disapproval or offense.

Equipment

Though aircraft sky diving gear had been used through 1980, in 1981, to ensure "equal opportunity deployment", more appropriate equipment was developed for lower altitude objects, particularly since most BASE jumps were then being made from sites much more challenging than El Capitan. Fast, on-heading parachute deployment is one of the most important needs of the fixed-object jumper, so Jim Handbury created a harness and Velcro-closed container system from a normal parachutist's harness with a modified container arrangement. Originally, it was designed just for smaller round canopies for low jumps from bridges over water, but with use, it quickly became apparent that it was also a somewhat superior container for jumps with larger square canopies from sites as high as 1,000 feet over land. While the regular sky diving container retained better reserve capabilities from higher sites over land, the simplifications of the Velcro-closed BASE rig reduced the chances of needing a reserve to the point that some jumpers no longer even consistently carry a second canopy.

The BASE rig is a regular custom-fit sky diving harness with a modified single container for the main canopy on the back and front-mounted D-rings on each main lift web for carrying a reserve. The leg straps have B-12 snaps for quick release in case of a water landing, and cut-away ability is retained for the three-ring risers. The main container is sized to fit the canopy snugly when i[t] is packed without a bag and takes up about 50 percent more space. For canopy line stowage, on the inside bottom half of the pack tray on each side, there is a vertical set of rubber band stows for the lines to be stowed horizontally from botto[m] to top over the main risers; outside on each side of the very bottom of the container are some extra rubber band stows for excess static line or just for temporary bridle and pilot chute storage for transport to the launch site.

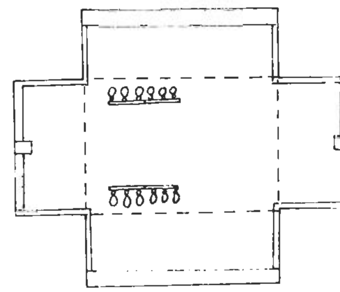


Fig. 1 Pack tray inside of BASE rig

The container is closed by four large trapezoidal flaps; opposite flaps are of equal sizes, and the side flaps are attached to two- to three-inch rectangular side panels. Each flap has vertical strips of Velcro that form a rectangle for mating Velcro when the side flaps are folded over both th[e] top and bottom flaps and pulled toward, but not to the center.

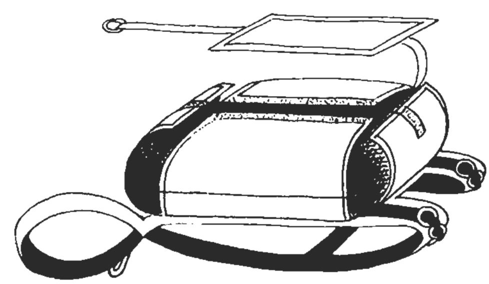


Fig. 2 Outside of BASE rig

The closing, mating Velcro is centered on a three-foot-long bridle line that attaches at one end to the top of the main canopy and at the opposite end to another bridle line for the pilot chute. The rectangular Velcro piece measures about four by ten inches and is attached to the one- to two-inch-wide bridle by sandwiching the bridle between a piece of matching-size fabric and the wrong side of the Velcro and stitching around the perimeter except only securing the bridle on one end. The free-running end of the bridle allows the Velcro t[o] peel off in either direction and prevents having t[o] deal with Velcro's much stronger shear resistance if the jumper were to deploy in an awkward or head down position.

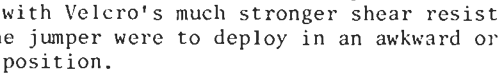


Fig. 3 Mating side of closing flap of BASE rig

Fig. 4 Exposed side of closing flap of BASE rig

The main canopy, a lightweight, F-111 nylon am-air square or modified round, is chosen ccording to the demands of the site to be jumped. round is often chosen for low-altitude sites ither where a short free fall delay before eployment would leave a jumper in very close roximity to the object or where there may be xcessive turbulence for a ram-air canopy. Not nough jumpers seriously consider these and other dvantages of a more forgiving round over a square nd instead choose the more familiar and readily vailable, faster-opening, but less forgiving quare. Both types of canopies have been used rom objects as low as 66 feet over water, and oth have performed excellently depending upon the eployment method used. Though rounds could also e considered, the more steerable squares are lmost exclusively used at sites higher than 600 'eet, which can accommodate up to a four-second 'ree fall. Below that, the free fall is shorter, nd static line and direct bag deployments come nto use, meaning that if a ram-air square were to ccidentally open off-heading, facing the object, here would be very little time to correct the ituation, and actual contact with the object is usually slower and therefore less serious with a ound.

Since fast and on-heading openings are the two ost important aspects of canopy deployment in ASE jumping, a number of tests have been done sing different techniques and canopies from arious altitudes over both land and water. With a wo-second free fall, a ram-air square packed lider-down in a normal pin-closed sky diving rig nd deployed with a regular 36-inch pilot chute an fully open in 250 feet. Yet, freely packed in static line deployed BASE rig, it can open in as ittle as 60 feet. F-111 rounds can fully open in 10 feet when packed in a free-bag-type system with ree-stowed lines and free fallen with immediate elease of a 36-inch pilot chute. For either ounds or squares, there is little effective ifference in opening altitudes whether static line r free bag deployment is used.

Though not widely used, hand-held release is lso a successful deployment method for smaller, ive-cell ram-air squares and for unmodified ull-down-apex rounds of 16 feet or less. The anopy is folded carefully to catch air quickly, quares with the nose folded around, and the lines re left hanging freely or partially folded and and-held with the canopy. Immediately upon aunch, the jumper throws the bundle up, and the anopy is fully open within 60 feet. However, nmodified rounds have a severe oscillation endency and are therefore not ideal for use near ess-than-overhanging objects, and these smaller ounds are designed to be used over water only.

In 1981, a large size pilot chute became tandard equipment for low-altitude BASE jumps and ll Velcro-closed BASE containers. At 48- to 52- nches with large mesh, a slightly pulled-down pex, and a bridle line at least eight feet long, he pilot chute supplies an estimated four times he drag of a normal 36-inch pilot chute at 60 iles per hour, or three seconds of free fall. While a 36-inch pilot chute does not have enough snatch force until the third second of free fall t release the pin on a pin-closed container, the 52- inch pilot chute will begin opening a Velcro-close container within the first second. With this high drag pilot chute, a square main packed in a BASE rig can be free fallen for two seconds and still b fully open within 150 feet, cutting approximately 100 feet off the opening altitude required with a pin-closed container and a regular pilot chute.

Reserve canopies vary from normal piggyback square or round sky diving reserves to chest-mount round hand glider reserves or harness-connected hand-held reserves. The best tested and most reliable are the regular sky diving reserves and t hand-held reserves. The sky diving reserve is use for BASE jumps generally above 1,000 feet, while t small, hand-held reserve is designed for very low sites and to slow a jumper only enough for an acceptable feet-first water landing. The hand-hel reserve is an unmodified pull-down apex round, usually measuring only six or eight feet. It is connected to the main lift web by a carabiner and held like a pilot chute, except in the opposite hand, ready for immediate emergency release.

The chest-mounted hang glider reserve is the most popular but not the most reliable reserve system in use with the BASE rig. It typically use an unmodified, 18-foot, pull-down-apex or regular 22-foot round canopy that is connected to the jumper by a single long bridle, up to 20 feet, and is therefore unsteerable. It was adopted in 1980 for sites too low to consider cutting away a malfunctioned main canopy. Theoretically, the fre bagged hang glider reserve could be pulled from th chest and thrown out to deploy above and safely beyond the fouled main canopy. When minimum testi was done with a normal square main canopy, the rou stayed clear but caused the square to dive nearly straight down, increasing the rate of descent. Still, most jumpers seem to consider the chest- mounted hang glider reserve acceptable for normal use with a BASE rig, even though no testing or use has occurred under actual low-speed malfunction circumstances.

Canopy packing techniques for BASE jumps vary but generally do not deviate excessively from aircraft sky diving pack methods. For a BASE jum above 1,000 feet, the packing technique often need not be changed at all, but below that, or if a BASE site allows only a three-second or less free fall delay, the main canopy, square or round, is packed without using any Opening Shock Inhibitors slow the deployment. The alterations to the usua packing procedures for a round canopy for a BASE jump generally consist of not using the diaper or other Opening Shock Inhibitor, not folding the canopy skirt 45 degrees on each side, and placing rubber band about four inches down around the ape to help speed initial inflation. For a jump lowe than 1,000 feet with a square main, the slider is almost always packed down, the bag, strap, diaper or other similar device, is left off, and the canopy is packed perfectly symmetrically with all of the lines pulled taut to help preclude line-wh and the possibility of a line-over malfunction. The nose of the canopy is usually either simply folded on its side underneath or opened and split symmetrically to either side, but there is some question as to whether or not the latter method increases the chances of any single cell being ab to direct the canopy off-heading on opening. The brakes are always set, and a variety of settings can be added so that if a canopy tends to ckslide or surge on opening, it can be rrected for in packing. However, the tail of e canopy and especially the steering lines have cessive pressure put upon them during a slider-wn opening, so the brakes must be treated very refully since it could be fatal to lose a brake en opening next to a fixed object.

Particularly, older, heavier, and larger uare canopies can be prone to backsliding on ening, and round canopies appear to backslide ightly before secondary opening; canopies of wer construction seem to need monitoring for aker steering lines; and high-aspect-ratio uare canopies, especially those with more than ven cells, have different opening characteristics d are prone to line-whip and line-over lfunctions when packed slider-down. By rerouting e steering lines outside of their keepers and owing them with pin-locked ("Zoo") toggles, a eering line can be released if it is fouled, and e canopy can be flown with rear risers, but this thod is used by few jumpers, and the added safety temporary steering line keepers has not yet been lly developed. Poor canopy pack methods are the imary causes of off-heading openings, and ymmetric or unstable body position is secondary. ile there is general agreement among BASE jumpers to the proper body position, there are still ffering opinions on optimum packing procedures, pecially for the wide variety of square canopies.

cations

The most important factors involved in lecting a jumpable BASE site are sufficient titude, lack of obstacles, proper wind nditions, and a good landing area. Altitude is nerally first checked on topographic maps, rcraft sectional charts, or construction ecifications. Then, a cross-check and test for stacles that may be encountered during free fall made by timing rock drops from the selected unch site. Oranges actually fall at the same neral rate as a jumper and are easier to see than cks and therefore give more accurate free fall lues when used for drop tests, but due to their requent unavailability, rocks are more practical use. Even though a rock has a greater mass than jumper, it will give a more conservative but ill quite acceptable estimate of altitude free llen. Since a jumper's track and acceleration ay from the side of a fixed abject does not ignificantly take effect until after seven seconds free fall, if the orange or rock drop-tested rikes a protrustion sooner than seven seconds, it y indicate an unavoidable free fall obstruction. e jumpable altitude can be calculated similarly the figures represented in Table 1 which are sed upon jumping from El Capitan under the llowing conditions*:

Landing area altitude — 3,976 feet asl
Free Fall Reference Velocity — the maximum (terminal) velocity a jumper would reach if he were at sea level; 98 miles/hour
Jumper mass — 180 pounds
Jumper velocity at launch — 3 miles/hour
Launch altitude above landing area — 3,060 feet agl
Air temperature at launch — 55 degrees F
Barometric pressure at landing area — 25.87 inches of mercury
Air temperature at landing area — 80 degrees F
Relative humidity at landing area — 50 percent
Corrected barometric pressure — 25.67 inches of mercury

Table 1 Free fall reference table for time, distance, and velocity

Time (seconds)	Altitude free fallen (feet)	True velocity (miles/hour)	Forward Throw (feet)
0	0	3	0
1	16	22	4
2	63	42	9
3	137	59	12
4	233	72	16
5	347	83	19
6	475	90	22
7	612	96	24
8	755	99	26
9	903	102	27
10	1,053	104	28
11	1,206	104	29
12	1,360	105	30
13	1,514	105	31
14	1,669	106	31
15	1,824	106	32
16	1,978	105	32
17	2,133	105	32
18	2,287	105	33
19	2,441	105	33
20	2,595	105	33
21	2,749	105	33
22	2,902	104	33
23	3,055	104	33

Spit is a good indicator of wind intensity and direction for the first couple hundred feet. Even if the wind is not in the optimum direction, if its intensity is not too great, inferior wind conditions can be corrected for to a certain degree upon launch by jumping more cross-wind rather than with the wind. However, the jumper can still be pushed by the wind in free fall, and upon deployment, proper canopy heading and sufficient penetration can become even more critical. Also, many fixed objects, depending on their geographic location, pass through more than a single wind intensity and direction at various levels. Often, the wind can be calm on the ground while increasing with altitude and possibly even distinctly changing direction. These factors can frequently be studied while climbing antenna towers and buildings under construction, but other objects may need to be checked by Wind Drift Indicator or consultation with hot air balloonists or similar pilots who use the area. Where thermal conditions can present problems, most jumps are made around sunrise, before such activity begins, and recently, some successful tests have even been begun to investigat the possibilities of packing the main canopy with offset steering line settings to cause it to open in a slight turn into the wind.

The BASE Jump

In an actual BASE jump, the launch shares primary importance with canopy packing. Once a jumper has ensured a quick, on-heading opening, stability becomes the main concern for the jump.

(See footnote at end.)

ough running or taking a few steps up to the it can help stability, it could also compromise ., especially in the case of an uneven launch oint where a misstep could occur. Therefore, it s often safest to execute a standing launch. To chieve proper body position, the jumper pushes ff with his gaze fixed on the horizon: head up, hest out, knees slightly bent, back arched, and arms up in a spread-eagle position. Many first-time BASE jumpers do not fully comprehend how important it is to look straight out at the horizon in order not to fall into an improper, head-down position. By remaining in a fixed position after exiting properly, the jumper will be pulled by gravity into a stable prone position after two seconds. Most experienced sky divers discover that there is insufficient airspeed built up to facilitate correcting instability until after the fourth second of free fall. Though it is best to assume the tracking position as soon as possible, about the third second, no significant movement away from the object will be evident until almost the seventh second when the track "kicks in" and the jumper attains lift and rapidly begins to move away from the object. To avoid having his shoulder straps slip off at opening shock, the jumper is careful to reduce his track before deployment, and upon opening, the jumper checks to see which way the canopy is facing and, if necessary, can use rear risers to initiate the fastest emergency turns. If more than one jumper has exited, either vertical or horizontal separation is achieved before the canopies are deployed.

Future Progress

To date, BASE jumpers have leapt from buildings, ships, antenna towers, smokestacks, water towers, bridges, aerial cable cars, cliffs, interior domes, and from numerous other fixed objects. Of the approximately 2,500 BASE jumps that have been made worldwide, about 75 percent have been at authorized sites, notably from the New River Gorge Bridge and from the cliffs, El Capitan, Canyon de Chelly, and Trollveggen. The U.S. BASE Association continues to help organize authorized BASE activities and disseminate technical information for any type of BASE jump. Currently, the USBA is seeking to have organized cliff jumping activities once again allowed at the safest and most accessible site, El Capitan.

As of August of 1986, 128 jumpers from around the world have completed BASE jumps from all four object categories. Jumps have been pioneered from nearly every different kind of jumpable object except for trees, and only the antenna tower category has yet to include authorized jumps. In June of 1984, the liability insurance hurdle was finally overcome during the organization of the first sport building jumps, so now the way has been paved for organized authorized jumps from all sorts of objects. Already, a number of non-jumpers are making BASE jumps safely from bridges into water, and two have even continued to literally work their ways up objects and into aircraft sky diving. Having only made a couple of additional hot air balloon jumps, one of these two initiates is already closing in on making his one hundredth BASE jump. With the advent of public vertical wind tunnels and the new sport of canopy soaring, with individual instruction, it is now possible for non-jumpers to get all the free fall and canopy experience they need to safely start BASE jumping without previous aircraft sky diving experience.

As limitations continue to be dissolved, BASE jumping is bringing the sport of sky diving directly to the public. As a spectator sport, its fine accessibility from launch to landing makes it one of the few aerial activities that can inspire and involve an onlooker nearly as much as a participant. Aside from its sporting qualities, its constructive potential will some day be fully understood for emergency uses such as high-rise fire evacuation and construction mishaps (BASE jumpers can easily fall past safety nets that are set up to catch objects falling from buildings under construction). BASE equipment is already as light as 12½ pounds, and with possible future advances to ram-air Rogallo-principle Paradactyl type canopies, even lighter, more efficient, and faster opening canopies are on the horizon. With more efficient air flow concepts, ram-air cells may become smaller and more numerous and may eventually lead to a still purer type of self flight in the form of ram-air jumpsuits. Until then, BASE jumping is the next giant leap for mankind, and the first step is a doozy.

Footnote

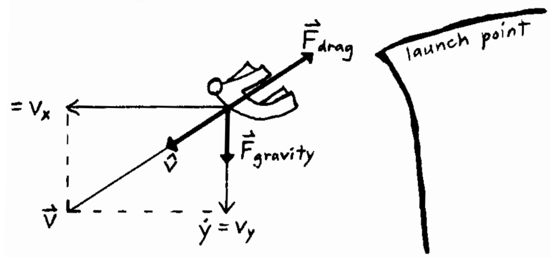
The values represented in the table are calculated from formulas based on a jumper starting from rest and falling in the same position throughout free fall without tracking. This is represented by the following diagrams and formulas from Philip de Loreilhe's master's thesis in applied mathematics (which has a liability disclaimer attached for anyone else's use of the calculations): *Determination of the Coefficient of Drag of the Human Body Using Natural Free Fall.* (University of Southern California, Department of Mathematics, 1987).

Symbols (in order of appearance):

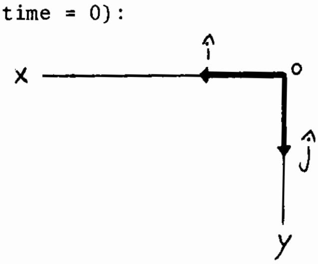
- $f[y]$ denotes any function f whose argument is y
- F = force
- v = velocity
- $\hat{v}$ = unit vector of the velocity
- x = forward throw
- y = altitude loss
- $\dot{x}$ = velocity in the x direction
- $\dot{y}$ = velocity in the y direction
- Y = height from ground; altitude agl - y
- $\hat{\imath}$ = unit vector in the x direction
- $\hat{\jmath}$ = unit vector in the y direction
- m = mass of jumper
- $\vec{a}$ = acceleration vector
- $g[Y]$ = acceleration due to gravity at altitude Y $= g_0 \frac{R_\oplus^2}{(R_\oplus + Y)^2}$ where $R_\oplus$ is the earth's radius and g_0 is the value of gravity at sea level
- A_e = effective area of jumper
- P = pressure $= \frac{1}{2} C_D \rho[Y] v^2$, due to convention used in aerodynamism
- C_D = coefficient of drag
- $\rho[Y]$ = air density at altitude Y
- $\ddot{x}$ = acceleration in $\hat{\imath}$ direction

$\ddot{y}$ = acceleration in $\hat{j}$ direction
$V_{max}[SL]$ = maximum velocity at sea level
g_o = acceleration due to earth's gravity at sea level
ρ_o = air density measured at sea level
$P[Y]$ = pressure at altitude Y
P_o = pressure measured at sea level, corrected for humidity
M = molecular weight of air
R = gas constant
T = temperature in degrees Kelvin
T_o = observed temperature at altitude Y_o, sea level
b = negative value representing a loss of temperature; the standard is $b = {}^{-}0.0065$, implying a loss of 6.5 degrees Celcius per 1,000 meters

This figure represents a jumper right after unching and shows the forces in action and the locity $\vec{v}$ split into its two components:



he origin of the axes is located at the start of he jump (time = 0):



he values are calculated using

$$\vec{F}_{gravity} + \vec{F}_{drag} = m\vec{a}$$

nd

$$\vec{F}_{gravity} = mg[Y]\hat{j}$$

$$\vec{F}_{drag} = {}^{-}A_e P\hat{v} = {}^{-}\tfrac{1}{2}A_e C_D \rho[Y] v^2 \hat{v}$$

hich become after simplification

$$mg[Y]\hat{j} - \tfrac{1}{2}A_e C_D \rho[Y](\dot{x}^2+\dot{y}^2)^{\frac{1}{2}}(\dot{x}\hat{i}+\dot{y}\hat{j}) = $$
$$= m(\ddot{x}\hat{i}+\ddot{y}\hat{j})$$

plitting the above vector equation into its two omponents gives these two coupled second-order on-linear differential equations:

$\hat{i}$ direction: $\ddot{x} = -\frac{1}{2}\frac{C_D A_e}{m}\rho[Y](\dot{x}^2+\dot{y}^2)^{\frac{1}{2}}\dot{x}$

$\hat{j}$ direction: $\ddot{y} = g[Y] - \frac{1}{2}\frac{C_D A_e}{m}\rho[Y](\dot{x}^2+\dot{y}^2)^{\frac{1}{2}}\dot{y}$

erminal velocity is reached when both components f the acceleration, $\ddot{x}$ and $\ddot{y}$, equal zero, and his condition is achieved when the two forces in ction, $\vec{F}_{gravity}$ and $\vec{F}_{drag}$, balance each other:

$$V_{max} = \left(\frac{2m}{C_D A_e}\,\frac{g[Y]}{\rho[Y]}\right)^{\frac{1}{2}} = V_{max}[Y]$$

rom the last equation, V_{max} depends on the ltitude since it relies on both $g[Y]$ and $\rho[Y]$, which vary. So, V_{max} is standardized at sea level (although that is an altitude no sky diver ever wants to find himself at in free fall!). Hence,

$$V_{max}[SL] = \left(\frac{2m}{C_D A_e}\,\frac{g_o}{\rho_o}\right)^{\frac{1}{2}}$$

Note that

$$\frac{C_D A_e}{2m} = \frac{g_o}{V^2_{max}[SL]\rho_o}$$

and the two differential equations become

$$\ddot{x} = -\frac{g_o}{\rho_o V^2_{max}[SL]}\rho[Y](\dot{x}^2+\dot{y}^2)\dot{x}$$

$$\ddot{y} = g[Y] - \frac{g_o}{\rho_o V^2_{max}[SL]}\rho[Y](\dot{x}^2+\dot{y}^2)\dot{y}$$

In modeling the earth's atmosphere,

$$P[Y] = P_o e^{-\frac{M}{R}\int_{Y_o}^{Y}\frac{g[z]}{T[z]}dz}$$

It is valid to treat the air as a perfect gas sinc staying well below 90 km of altitude, so

$$\rho = \frac{M}{R}\,\frac{P}{T}$$

hence,

$$\rho[Y] = \frac{M}{R}\,\frac{1}{T[Y]}P_o e^{-\frac{M}{R}\int_{Y_o}^{Y}\frac{g[z]}{T[z]}dz}$$

where

$$T[Y] = T_o + b(Y - Y_o)$$

The values from the table were obtained by solving the two differential equations by a fourth-order Runga-Kutta algorithm.

Bibliography

1 Poynter, Dan. *Parachuting, The Skydivers' Handbook*. Santa Barbara: Parachuting Publications, 1978. pp.41-53.