BASE MALS:

Tension knots, canopy reliability statistics, & design progression

By the SQ/AD Team

(version Française ici)

Tension knots could be the scariest and least understood BASE malfunction. Caused by an entanglement of lines during deployment, a tension knot can result in an uncontrollable canopy forced into a high descent-rate turn, stall, or asymmetric stall. The exact causes have remained unclear throughout the 40 year history of BASE, yet most BASE jumpers can tell you at least a couple of things that supposedly contribute.

In an effort to increase understanding of rates of occurrence, we surveyed BASE jumpers in 2019, and conducted a more than year long study during 2020-21. Getting a large enough sample to gather adequate data for strong conclusions may be impossible, but this is a start. Thank you to the jumpers who took the time to answer our questions and contribute to this research.

This is by no means a conclusive study, and is only part 1 of what we hope is a more thorough effort by the community to understand tension knots. It is not easy to reliably **create** tension knots on-demand using normal packing techniques. Until a phenomenon can be reliably created, it's difficult to identify major individual factors.

In the short term, we aim to:

1) Suggest techniques for dealing with tension knot malfunctions
2) Allay fears about factors that don't seem to be major causes
3) Bring your attention to factors which may be significant

While the 2019 survey was useful, the bulk of progress that has been made is the result of two years of test jumps using a variety of gear configurations, sliders, and line plans. Using the information collected during this study, we are endeavoring to develop equipment designs with decreased tension knot potential.

Back to the surveys: three were conducted. The first was to SQRL customers only, specifically those who had purchased major BASE gear elements (a canopy and/or harness-container system). The second (V2) was posted publicly. 540 jumpers responded to the surveys in total and over 70% of the respondents reported BASE jumping "within the past few weeks" (i.e., mostly current jumpers). A total of 248,752 BASE jumps were reported between the two studies. The third survey was smaller and more targeted, asking 160 people who jumped a 2020 version of brake line configuration on one specific model of canopy, with 17,093 BASE jumps reported.

Frequency of Occurrence / Clearance

About 10% of survey respondents reported at least one tension knot in their jumping career.

Of the tension knots reported, 62% cleared or were cleared by the pilot, prior to landing. The other 38% either "landed" or "crashed" with the tension knot unsolved. Of the knots that cleared, about half of respondents said it cleared because they acted – usually with an aggressive riser or toggle input on the affected side.

The jumper flying the tension knot shown above said: *"I pulled the riser down to my shoulder and dropped it to induce slack & it popped out… 3 seconds total."*

The data here is clear: **most** tension knots do clear, and many tension knots can be cleared with **action**. A review of the tension knot videos available indicates that doing nothing doesn't help.

Solving a tension knot is sometimes possible by re-introducing slack into the line set. We can do this by large & aggressive toggle and / or riser inputs.

Awareness and Action

- No input = No solution.
- TRAIN: PRACTICE THE RECOVERY **BEFORE** YOU GET A TENSION KNOT.
- DO SOMETHING WHEN YOU DO GET ONE.

- NEVER. GIVE. UP.
- Remember*: "We do not rise to the occasion, we sink to our level of training."*

Not all tension knots are solvable. If the tension knot is severe, and the turn / spin is very fast, the event is highly disorienting.

However, a surprising number of tension knot videos show the pilot under-reacting to a mild turn, and evidence points to most tension knots being recoverable / clearable. So why do some jumpers underreact?

1. A lack of recognition: some pilots "feel" a problem in the parachute, but fail to accurately diagnose it or do not attempt to diagnose it (i.e., they don't look up).

   Solution: Know what a tension knot looks like, and look at your canopy.

2. A lack of knowledge of how to fix a tension knot.

   Solution: Study what has worked for other pilots in the past, and try every known remedy.

3. Preoccupation with landing: The importance of "where to crash" increases as available altitude decreases. But it is rare that an opening occurs too low for one look upward, and at least one recovery attempt. You may not be high enough for 10 attempts, but try at least once.

   Solution: Open high enough to deal with a problem, and maintain altitude awareness as you deal with it - remember that you do have a reasonable chance of solving the tension knot with some effort, but no chance of solving it with zero effort.

<u>What to do (remedies)</u>

1. Vertical speed control: Fly what you have and try not to let your parachute "wind up" into a fast turn, (spiral, spin) by using counter-inputs. Use the opposing brake until near-stall, in order to stop an accelerating or fast turn.

2. Heading control: Try to control where you land, or what you hit. Remember that as wingsuiters & trackers we do have some control of what we open over. Even a small adjustment in a hazardous area can make the difference between minor and serious injury.

How to practice:

"If you never practice pulling down your rear risers and then dropping them, for example, then you won't have the skills needed when you have a tension knot. You won't have time to learn these skills in the stressful seconds of your first TK malfunction. So, practice" -Will Kitto

Become proficient at stalling your parachute on brakes. A full stall can momentarily relieve tension on C/D lines.

Become proficient at stalling your parachute on risers. Full riser inputs followed by release can provide a tension change that allows a knot to free.

Become proficient at performing an asymmetric stall or “helicopter” using all possible controls: Risers with Brakes set, Risers with Brakes released, and Brakes alone. Understanding this maneuver and the amount of riser or brake input needed to spin your canopy will help you use the same input to counter or deal with a TK.

Practice large, aggressive, single riser inputs, to learn how much input can be given and to what effect. When you have a tension knot, you cannot pull the affected rear riser “too far” down.

An understanding of stall and spin maneuvers will allow you to recognize how much control input is possible to counter a tension-knot-induced turn. You should be familiar with these large inputs, and stalls, which are methods that have worked for other jumpers.

These drills are best practiced in the skydiving environment, with your BASE canopy packed as a main in a student rig or similarly large container system. Your local DZ rigger will probably be glad to help. See this video on practicing BASE canopy skills.

What Causes Tension Knots, Anyway?

The most common entanglements are between the brake lines and the C/D line groups, and very often involve the line bifurcations. The slider plays a major role in tension knots, locking in or setting tangled lines as it descends.

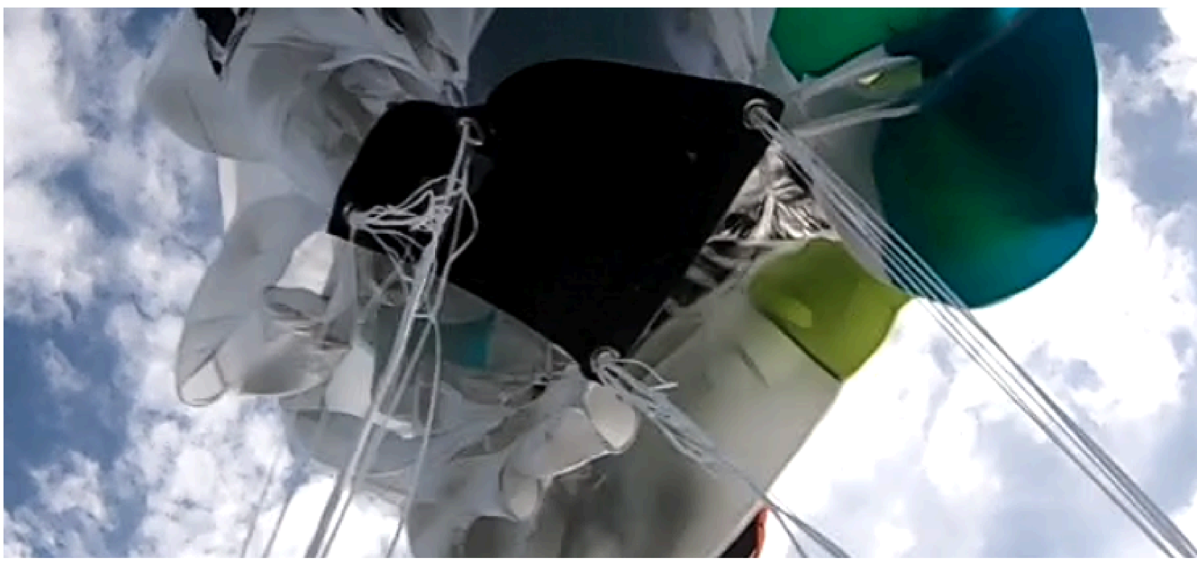
These entanglements often occur after line stretch, and before slider descent. Commonly, the main and upper brake lines orbit or rotate around the C/D line groups. Because there is comparative slack in the brake lines (due to brakes being set, and the brake lines in total being longer than the C/D lines), they are often free to dance around until the canopy expands enough spanwise and chordwise (particularly at the trailing edge) to tension them.

Ideally, as is common in the openings of most skydiving canopies, the tangled lines will “shake out” into untangled and well-tensioned columns prior to slider descent.

A rapid or too-early slider descent, particularly in cases where the opening is asymmetric and the slider itself is asymmetric before it begins its descent, is a significant causal factor.

Parachute lines are inherently disorganized in the early phases of the opening, shortly after line-stretch. As expansion begins, and the slider and parachute begin to open and spread out, the lines begin a process of sorting and organization. If the lines don't "shake out" into organized parallel columns through each slider grommet **before** the slider begins to descend, then the slider can "lock in" or "set" the entanglements as it (prematurely, it could be said) descends the lines.

A progressive, staged, and symmetric opening gives parachute lines the best chance of organizing into parallel and direct paths from risers to attachment points, with tension applied to the brakes & C/D lines as a result of **even canopy inflation before slider descent**.



Bad: An intentionally hard opening using an oversized PC and long delay during our study. When the slack rear lines shown here orbit around the tensioned lines and then the slider descends, it adds pressure to the tangles while allowing the line groups to expand and pull apart just above the slider grommet as it descends.
Asymmetric expansion & inflation of the parachute is a primary cause of line slack. If the rear part of the chord expands out of sequence (on one or both sides) with the front of the canopy, there is inadequate tension placed on the brake line groups, leading to slack.

Good: Symmetric expansion and inflation of the parachute, lines tensioned and organized from risers to lower surface. In contrast with the previous photo, the rear part of this canopy's chord is inflating and pulling tension with organized brake lines. A slider gate is shown in use.

The statement, *"Sliders are the leading cause of tension knots in BASE"*, is partly true. It's worth thinking outside the box on slider type, design, & function in our sport - what can be improved? The correct answer is "something". TKs affect all BASE canopies and sliders were involved in 99% of TKs reported.

Opening speeds are a factor in TKs. Premature slider descent is a significant factor in tension knots. The lines of the canopy need time to "shake out", and organize into parallel groups before the slider begins to descend.

If the slider descent is too early, it can "set" the tangled lines that have not yet been brought to a state of **organized tension**.

- Pack your canopy while maintaining tension from the top surface of the canopy to the risers.
- Configure your equipment (slider type & size, and PC size) to prevent premature slider descent.

- Make great efforts to pack symmetrically: line disorganization is more likely to occur during asymmetric canopy expansion / inflation.

There needs to be more dialogue on the benefits of moderating opening airspeed and choosing PC size and slider type in order to encourage more progressive openings. Any opening that results in a premature slider descent should be diagnosed and corrected in future jumps with proper gear configuration.

For slick and tracking jumps at terminal airspeed, BASE jumpers should make greater use of:

1) Smaller sized PCs: 32” is ideal for most canopies for slick and terminal tracking jumps. Modern BASE canopies weigh less and open faster. These design developments call for smaller PCs than traditionally prescribed. A 38” PC is **not** appropriate for a terminal slick or tracking jump.
2) Hybrid-sail sliders: particularly for vented canopies designed with low freefall performance in mind. Sail sliders became taboo before tracking suits, when BASE jumpers were consistently opening near to walls and heading was more critical, and heading performance was lower. Today’s modern BASE canopies provide better heading performance with sail and partial-sail sliders and today’s jumpers are opening further from the wall in most cases -- and moving to tracking suits earlier in their progression.
3) Airspeed control: pulling from a high speed track increases risk, either slick or with any type of tracking suit including one-piece tracking suits. Decelerate before deployment by adjusting your body position and angle of attack on every jump.

The Tension Knots That Were Reported

60 total tension knots were reported by 59 of the 540 respondents in the initial surveys (one jumper reported 2). Of the 60 tension knots, 59 were slider up.

Types of Jumps

99% of respondents were packed slider up when they had their tension knot:

- 53% were flying a wingsuit*
- 23% were tracking
- 23% were slick

*It would be incorrect to infer from this that a TK is more likely when flying a wingsuit. The Survey did not separate out the total career number of WS jumps vs slick or tracking for each respondent.

Types of Lines

- 71% of tension knots occurred on Dacron line sets.
- 25% of tension knots occurred on Spectra line sets.
- 4% Other

Without industry-wide sales stats we can't be sure, but this seems to be roughly in line with the current distribution of line types on canopies in the wild.

PC Size

- 34: 2%
- 36: 23%
- 38: 41%
- 40: 2%
- 42: 10%
- Remainder: (Don't remember, unsure, did not answer)

Many more potential questions here, mainly: what was the airspeed at deployment for each size of PC & what was the weight of the canopy? To be cross-referenced with packing technique and reefing configurations.

Number of jumps on the line set

We only asked this question in the second survey, so the data is suboptimal here. 64% of respondents who were asked this question reported that their tension knot occurred on a parachute with less than 100 jumps.

- Less than 10 jumps on the line set: 20%
- 10-50 jumps: 24%
- 50-100 jumps 20%
- 100+ jumps: 36%

*It's intuitive that well-used and fuzzy lines would have a higher friction coefficient and therefore be more prone to TKs. As stated above, the data here is suboptimal and we don't see conclusions to draw from it.

Slider Type

- Fine Mesh 45%
- Large Mesh 26%
- “Slow” Slider 11%
- 18% “don’t remember”, or slider off

Most jumpers used control line restriction (tail-gates / slider-gates / tape)

- 63% of respondents used a form of tail gate or control line restriction.
- 36% did not.

This could be an indication of how many people use control line restriction, slider up. Or it could be an indication of control line restriction contributing to TKs. We don’t have enough data to form a recommendation based on this survey, but we continue to use some form of control line restriction (tape, tailgate, or slider gate).

A very subjective question was asked: Was the opening hard, soft, or normal?

- 30% answered that the opening was “hard”
- 40% answered that it was “normal”
- 20% answered that it was soft.

The subjectivity of this question is high (probably as high as the likelihood of accurate memory is low) but there is not an obvious pattern (i.e. the vast majority reporting that the opening was very hard or very soft).

Packing Recommendations

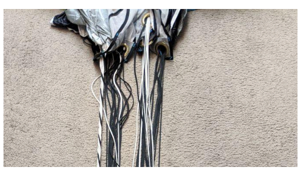
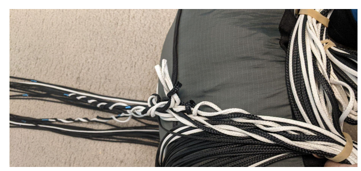
Line Tension. Packing under tension is important. Maintain tension from the top surface (packing tabs) to the risers until lines are fully stowed.

Primary Stow size and tension. We recommend the normal 2.5” to 3” (8cm) bight of lines, double stowed with a standard band. It is common to see primary stows that are insecure and prone to pre-release. A SECURE DOUBLE STOW IS IMPORTANT. One prominent BASE Jumper recommends two separate double stows, as in two rubber bands applied to the primary stow line bight. We think that’s not a bad idea.

Line stowing – sequencing and stacking. Remember in which direction the lines are paying out of the tail pocket: down. We recommend stacking lines from large to small, ***and also stacked from top to bottom*** of the tail pocket.

Line condition. BASE parachutes need frequent re-lining. 150 jumps is a common recommendation for control line set replacement, and ~350 for full line sets. Strength is a primary concern, but degradation of the braid (furring) is also a factor for replacement. While the survey data does **not** show that old lines overpower other factors, we do recommend replacing line-sets per the manufacturer recommendation and at the point of visible wear. This seems obvious, but is frequently ignored by BASE jumpers and leads to unknown consequences.

Twisted Brake lines. A common assumption is that a person who gets a tension knot must not have untwisted their brake lines. ***While twisted brake lines certainly can't help***, they also don't seem to be a primary causal factor. A measurable percentage of reported tension knots occurred with jumpers who are reliably confident there were zero twists in their brake lines. Anecdotally, we have been unable to create a tension knot by intentionally twisting brake lines up to 120 times per side. The theory that twisted brake lines are a primary cause of TKs is more like an old hypothesis that crumbles in the face of evidence.

		
Despite adding 120 brake line twists to this parachute...	To the point that one side's line group was 16 inches shorter than the other…	...it (repeatedly) did not result in tension knots or show more of a tendency to TK.

Slider & PC Size / Type. You cannot safely use one Slider and one Pilot Chute for all types of slider-up BASE jumps. A terminal slick jump deployment occurs under very different conditions than a wingsuit or subterminal deployment. Packing for high airspeed terminal slick and tracking suit jumps should include changing to a "slow slider" or a partial-sail slider. A smaller PC (down to 32" in most cases) should be used for higher airspeed deployments (terminal slick jumps being the best example).

Rolling the Nose. There has been some debate about how effective rolling the nose is. Our testing has shown that when properly applied, it makes a significant difference. **Tightly** rolling the outer 3 cells on each side of the canopy **many times** (video) and **tucking the rolls securely into the reduction folds** is an effective way to temper opening speed. This technique is recommended for high airspeed deployments, particularly with vented canopies. Video and accelerometer data show that rolling the nose, ***thoroughly,*** changes opening behavior on most canopies. Simply folding the outer three cells a little and then calling it “rolled”, does nothing.

Parachute Design Factors

Those who took the survey will remember that we asked participants for details about the parachute they used and when / if a tension knot occurred. An indication of propensity could be interpreted amongst the most popular models used by respondents, but the following must be taken into consideration:

1. Number of total jumps done on each parachute, not just the number of people who own it or are jumping it (only asked of half the respondents).
2. Number of jumps done slider up, or slider down (a parachute which is mainly jumped slider off will skew to a far lower TK occurrence per total jumps done because slider off tension knots are extremely rare - this can be solved by filtering results by % of jumping done slider up or down, which **is** a question that was asked).
3. Line type split (some parachutes are available with different line types, and this split was unknown outside of SQRL customers).
4. Respondent motivation. The survey links were non-unique, available publicly, and forwarded by recipients sometimes specifically to jumpers who have had tension knots. This skews the rate of occurrence and biases the results — in particular when the survey is forwarded specifically to someone who had a TK years in the past, eg. an Ace or Raven tension knot from ten or fifteen years ago.
5. Finally, reporting errors in a small sample size can have an outsized effect.

Many active BASE jumpers have multiple parachutes

670 canopies were represented in the 540 respondents. Of the jumpers we surveyed and their 670 canopies, the eight most popular models account for 86% of the total (574). Within these eight canopy types, we collected dimensional information from canopies in the field, and compared a wide range of design factors including:

- Relationship between C/D vs Brake cascades and associated D vs main brake line lengths (the interaction of line junctions leads to the worst entanglements)
- Bridle attachment point location on chord (no effect, no statistical difference, and no indication that attach point location changes outcomes)
- Brake setting “depth” (a factor in C/D slack during opening)
- Line type & diameter at each part of the line set (lines of drastically different weights do not like to interact (i.e. 900lb Dacron whipping past 400lb Dacron during expansion)
- Canopy trim angle (a factor in Brake line group tension vs C/D line group slack)
- Line attachment points on chord

- Aspect Ratio
- Slider Dimension & type (smaller sliders have worse outcomes, other factors being equal)
- Brake Cascade Type (staggered, single junction, etc)
- Venting
- Other factors

A note on bridle attachment point location: A facebook post presented the hypothesis that depending on bridle attachment point location, unequal tension will occur on the lines during deployment. We think this thought has merit, however the comparison with skydive reserves misses the fact that BASE canopies are usually stowed with deeper brakes and when brakes are stowed, the trailing edge is deflected, **which reduces tension on the rear line group**. Additionally, it’s not clear that the source of a tension knot can persist for so long after bridle tension goes to zero, which is immediately following line stretch, at which point line tension is influenced exclusively by drag force / relative wind. That said, we think that tracing the load path from PC to risers more accurately is an excellent area to apply research and we hope that this line of thinking leads to design improvements in future.

Causal factors summary: No single factor emerges as a “smoking gun” in the case of tension knot occurrence. Statistically, sorting reported tension knots by canopy design factors does not show reliable patterns. During two years of video analysis and attempted tension knot creation, no single design factor stood out as problematic.

Yet, themes emerge. The following points have informed our continued parachute development:

1) The interaction of brake lines with the C/D line groups, particularly at the C/D bifurcation point, should be reduced / mitigated.

2) Slider size and dimension is important. Larger sliders allow for better line reorganization prior to slider descent. Smaller sliders tend to create more slack in the C/D line group prior to slider descent.

3) Slider descent should be progressive, and should only occur **after** early inflation and expansion **has tensioned line groups equally**. Airflow must influence the rear part of the parachute chord symmetrically, tensioning C/D line groups as soon after A/B lines as possible.

4) Slider type and dimension should be re-considered.

We wish that it were as simple as moving a bridle attachment point or eliminating looped line junctions, or even better – untwisting your brake lines. The number of variables involved with each tension knot occurrence is higher than is commonly understood.

Matt G and his Hayduke 230. Photo by Richard Keir

What's Next?

We would like to restate our gratitude for the jumpers who helped us to gather information for this survey. Information sharing will be a key factor in making progress on this issue.

For more information on what steps SQRL is taking to improve our products in light of what we have learned from the survey data, read on.

Part 2: 6 Grommet (6G) Slider Testing

6 (or more) grommet sliders are not new to parachutes, and our testing indicates that they have a positive application in BASE jumping.

During the post-survey study period, we conducted test jumps using a variety of BASE canopy configurations, searching for tension knot formation and causes. As stated earlier in this paper, tension knots are difficult to create at-will. Our current theory is that the action of the brake line group rotating around or interacting with the C/D line group prior to slider descent is a primary cause. As the slider descends, and the upper lines begin to spread at the slider grommets, the tangles are “locked in”.

It is difficult to prevent brake lines from having more slack than the C/D group, and difficult to prevent some tangling of the brake lines with the C/D line group -- these issues seem to be a fact of parachute deployments across all types. So how should we maintain organization of these lines during and prior to slider descent?

The six grommet slider clearly & dramatically improves line organization. Not only does it reduce interaction between the brake lines and C/D groups, it also efficiently separates tangles and interaction between the groups when they do occur.

One obvious concern is whether the brake & C/D lines can entangle severely enough to prevent the slider from separating them, resulting in a hung slider. Two important questions were asked:

1) **Q: What is statistically more likely, a severe tension knot with a 4 grommet slider or a tangle below the grommets on a 6 grommet slider?**

   A: Video suggests that the 6G slider yields noticeably cleaner openings which leads us to posit that an entanglement of any kind is less likely when using a 6G slider. We have changed to 6G sliders for our personal jumping out of preference, based on testing so far.

2) **Q: Does a line entanglement below the grommets on a 6 grommet slider result in a *worse outcome* than a severe tension knot?**

   A: We tested this by creating unsolvable knots below the grommets on a 6G slider at the near-center, and also the outer span. The canopy rotation speed and sink rate was similar to a severe tension knot: if the knot is closer to center span, it can be manageable. If the knot is closer to the wingtip, the turn is rapid and disorienting just like a tension knot at that location.

These two points taken together show that the outcome of an entanglement below the slider grommets is nearly indistinguishable from that of a severe tension knot entanglement with a traditional 4 grommet slider. Yet, a 6G slider likely reduces the risk of entanglement in the first place.

As of this writing, the 6G slider has been tested in the BASE and skydive environments on BASE parachutes ranging from 190-350sqft in size with 100% of the deployments showing better line organization than with a traditional four grommet slider.

So far, there is no indication that the line groups have a tendency to entangle to a level that the 6G slider does not easily reorganize. In fact, the opposite is indicated – the brake line groups interact less with the C/D line groups, and when interaction does occur it is solved sooner by the 6G slider line organization.

For fun, we taped together the C/D & brake line groups, tied overhand knots in between them, packed parachutes in highly disorganized manners, and otherwise intentionally entangled the lines -- in every case below, the 6G slider descended easily:

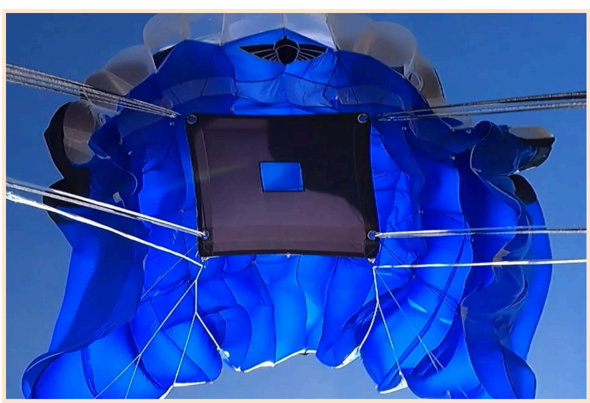
	
BR6 overhand-knotted to C/D group	10 wraps of 1.5” tape

	
25 wraps of 1" tape	15 wraps of 3" tape

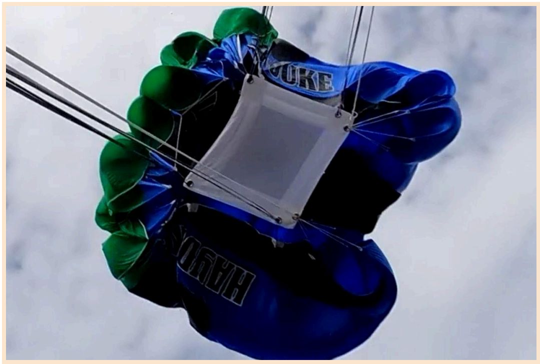
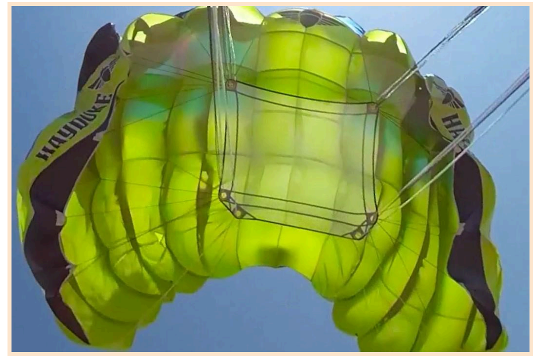
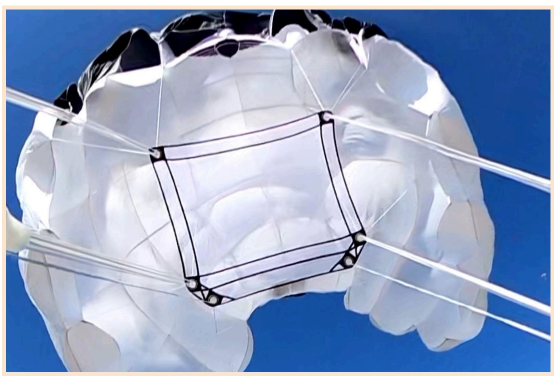
Wrapping tape around lines below the slider is not the same as a tension knot. A thousand jumps over a year is still early in the context of BASE. Testing is ongoing, but we have what we consider to be ample evidence that line organization is improved with the use of a 6G slider and there are many non-BASE examples of 6 and >6G (up to 12G) sliders performing superior to traditional 4G sliders.

6 GROMMET SLIDER TESTING: https://vimeo.com/697748087

Five versions of the 6G slider have been tested, with similar results.

	
Squirrel-manufactured RDS rings positioned on the trailing edge of this mostly sail slider act as the 5th and 6th grommets on this version.	Six traditional grommets, with edge-to-edge fine mesh and a central sail slider brake.

	
Six traditional grommets, with edge-to-edge fine mesh and central sail slider brake of a smaller dimension.	RDS rings positioned on the trailing edge of this fine mesh slider act as the 5th and 6th grommets on this version.
	
Two more images of the RDS ring sail version.	The SQRL RDS rings used in the slider example above: 

	
Six traditional grommets on fine mesh.	Six trad grommets, edge-to-edge fine mesh.
	
If you can tell what is different about this parachute compared to the others shown in this article, you get a cookie.	RDS rings and fine mesh.

	
RDS rings positioned on the trailing edge of this fine mesh slider act as the 5th and 6th grommets.	6 traditional grommets and edge to edge mesh with a sail slider brake (removable). The winning concept, thus far.

In Summary

While statistically very rare, tension knots happen often enough to be of concern. In our opinion the best preventative measures include taking steps to ensure symmetrical parachute expansion during deployment, using the correct (not oversized) size PC, controlling deployment airspeed, and embracing higher-drag sliders and new slider types.

Part 3: Tension Knots & Gear Development at SQRL

In 2019 & 2020 we conducted surveys of our customers and the BASE jumping public in an attempt to get a better understanding of tension knot occurrence rates. You should read that article first.

Here is a brief Q&A, in anticipation of questions from our fellow BASE jumpers:

Q. If you learned something about gear, what was it?

A. What seemed like a flare-up of TK reports in 2019 was the principal reason we launched this effort. Based on the number of jumps completed since 2017 the data indicates that the Hayduke is average in terms of today's BASE canopies, but talking about it was trendy for a season among some jumpers at Brento, and remains trendy years later at one BASE school in particular.

The Hayduke was the most strongly represented parachute in the survey, at 22% of the total, and 20% of the reported tension knots. The original Ibex (released 2014) was 7% of the total, and 11% of the tension knots (worse). *Other canopies held a higher percentage by canopy share*, *but were less strongly represented (still worse rates of occurrence, but lower data quality)*. Two canopies in the survey looked "better" based on the data.

There is no interpretation of the data that shows the Hayduke being worse than the average. If you view the data filtered by % of **slider up** jumps, the Hayduke in fact looks "better than average" in the list of canopies for which there were at least 30 respondents.

Regardless of the actual statistics, the study and subsequent testing effort sent us down a bit of a tension knot rabbit hole. For such a problematic (albeit rare) malfunction, very little is known about TKs. Leading representatives of leading brands cite twisted brake lines and messy line stows as primary factors, which we now know to be inaccurate. The conventional wisdom around tension knots is mostly false, and seems to have been passed down in the skydive cargo-cult the way many other myths are, such as slider grommet friction shrinking your lines and downwind turns.

So what are we doing? Our journey down the rabbit hole does seem to have led us to a better understanding of the issue, and the Hayduke 2's design, for example, has benefitted from this. Specifically in the area of TKs, we have focused on slider dimension / type, and how to stage openings better.

Q. Please send me all the raw survey data?

A. None of the parachute models in the survey appear to be a hazard to the BASE community, but there is a range of tension knot occurrence by model, so don't worry about it (but we do appreciate your well-meaning concern).

The sample size in BASE is inherently small. Other biases inevitably creep in, such as the selection bias of jumpers who have had tension knots being more likely to fill out a tension knot survey. More questions, more specific questions, and a larger sample size would improve data quality, but we have firm enough data on our own gear to make what we think are *safe assumptions* about parachute model performance. One assumption that we think is safe is that **the Outlaw looks exceptionally good in terms of low TK occurrence over the past 9 years.**

Why? The list of variables is long, with many design differences ranging from aspect ratio, degree of trim, brake cascade vs C/D cascade location, venting, full line plan dimensions, slider size & dimension, typical slider descent rate, etc. The progressive nature of the Outlaw's openings, with consistently center-span-first inflation, a large and low aspect ratio slider, and a slower slider descent than other vented canopies, all contribute.

Q. So what is SQRL thinking in terms of design improvements?

A. Since late 2019 we have been testing a new brake cascade and slider dimension for the Hayduke 1, alongside Hayduke 2 development efforts. Terminal airspeed Hayduke 1 opening comfort can be significantly improved by using a partial-sail slider of larger dimension, and 32-34" PCs.

The following video explains our recommendations for HD1 owners:

https://vimeo.com/701285881

Q. Any more recommendations?

During this study we focused on how important it is for the parachute opening to be staged. Lines require the opportunity to shake out and organize prior to slider descent. Before slider descent, the parachute needs time to expand symmetrically, particularly at the tail, to create the tension needed to reduce slack in the brake lines and allow organization.

For higher airspeed openings (terminal, tracking, slick, and some wingsuit deployments) we recommend the use of smaller PCs. In general, we think that 32” and 34” PCs are **underused**. 36” PCs should be reserved for the largest / heaviest canopies and 38” PCs are **almost never necessary** for terminal jumps. The advice to use a 38” PC for terminal jumps (i.e., Brento) is outdated. Additionally, sliders with higher drag, for example **hybrid-sail sliders**, should be used more often by BASE jumpers operating in the high deployment airspeed realm.

If you own SQRL BASE gear, please don’t hesitate to contact us for our recommendations.

Q. “5 Lines”? Why don’t you make it 4 like everyone else?

A. 4 lines aren’t inherently safer, or better. It is outdated and illogical to think that 4 lines means there is nothing to worry about. It is a fact that 5 lines = 1 more line to entangle than 4, but there are other more important design factors than 5 vs 4.

Q. But I definitely heard from this guy, who definitely knows everything, that five control lines is Black Death!

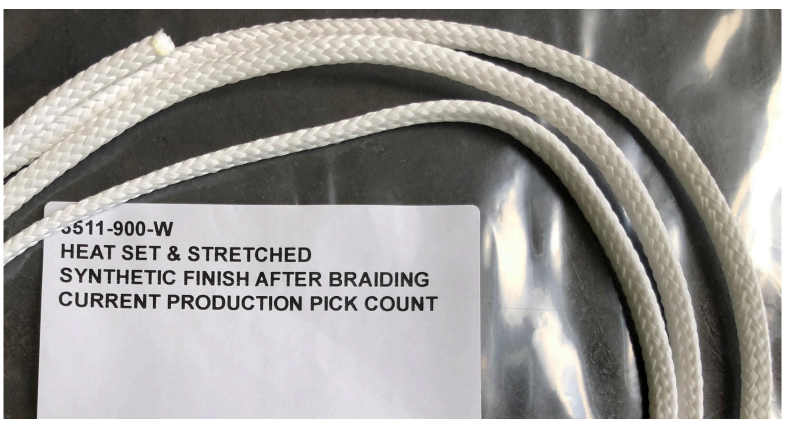
A. He doesn't know everything, but we sure wish someone did because it would be really nice to talk to someone who actually knows everything. Fear of five control lines originated with the Ace (an excellent canopy, overall), in the early 2000s. Several tension knots were reported on Aces built with a 5-to-1 brake line junction. One incident in particular sealed the deal in the public's eye when the legendary Karina Hollekim was badly injured.

Note that:

1) The size of the junction was formidable, with a 900 lb Dacron main brake line joining five 600 lb Dacron uppers. This stiff high volume junction is generally not considered a benefit.

2) The Ace's 5 upper lines were not all equal in length. This was also thought to be a cause of unequal tension during the deployment.

While it is logical and safe to say that TKs are caused by lines, so fewer lines is better, it is also factual to state that an almost industry-wide conformity to 4 lines didn't solve the problem – parachutes with 4 control lines experience TKs at the average rate. Meanwhile, for example, the Outlaw departed from the standard in 2012 and a 9+ year track record indicates that even with a 5-line upper brake configuration it has **performed better** than the average.



Q. What about line material? What if it's stiff or something?

A. This is a valid concern. The Dacron lines used by all BASE brands all come from the same place: CSR Braids, USA. Every BASE manufacturer uses the same Pick Count in the braid for each line weight, which undergoes the same Heat Set, Stretch, and Synthetic Coating treatments.

However, according to CSR Braids, the finishing process is more of an art than a science, and the results do vary -- particularly with the Synthetic Coating process. This can create a variance in the finished stiffness of the line.

Line that is too stiff is not a benefit. Line that is too supple is not great, either. We have seen enough of a difference in lines on our canopies, and others, to discuss this at length with the owners of CSR Braids and carefully monitor the condition of each line batch. Since 2020, we have reduced our tolerances for stiffness on CSR Dacron, especially for the 900lb weight used for the main brake line. This article contains more info on line types for BASE.

END

Tension Knot Mals

The following images are screen grabs from online videos of tension knot incidents. Logos are covered on non-SQ canopies.


Out 1,053: Tension Knot


Posted by [redacted]