Slider Drag Cancellation: Another Cause of Hard Parachute Openings

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(version 01-08-08)

Background

On rare occasions the ram-air parachute wings[+] used in skydiving open very quickly, and in manners that generate high opening loads.
In some cases, these openings have been hard enough to cause serious injuries.

Several mechanisms have been proposed to explain such events, including:

- **slider rebound**
- **off-staged deployments**
- **unsual canopy and slider folding/packing**

We wish to suggest another mechanism which, either on its own or along with the above mechanisms, will also lead to very hard openings: <u>Slider Drag Cancellation</u> (or "SDC")

[+]also called "parafoils"

What is Slider Drag Cancellation?

Succinctly, SDC is a condition that is:

- being created at the very beginning of inflation

- generating high pressure areas *above and below* the slider's surface

- impeding the slider's hability to remain at the top of the suspension lines thereby facilitating *bottom skin spreading;* bottom skin spreading is an extremely rapid inflation mode that generates high opening loads

In the next few slides:

1. How does a slider work in nominal openings?

2. How can slider drag be cancelled?

3. How to reduce the occurrence of SDC?

4. Concluding remarks

1. How does a slider work in nominal openings?

Reality check: parafoils do *need* inflation control devices for soft openings

Typically, inflation control devices such as <u>sliders</u> lengthen the duration of inflation (and canopy expansion), which in turns reduces the magnitude of the opening shock. Without sliders, the opening would be very fast *and* feel very hard.

Figure 1 (next slide) shows that the maximum opening forces sustained during the nominal openings of slider-reefed skydiving canopies are at about 3 - 5 g's

Without sliders such canopies sustain maximum opening forces in the range of 10 to 15 g's (and even more – see figure 1 again)

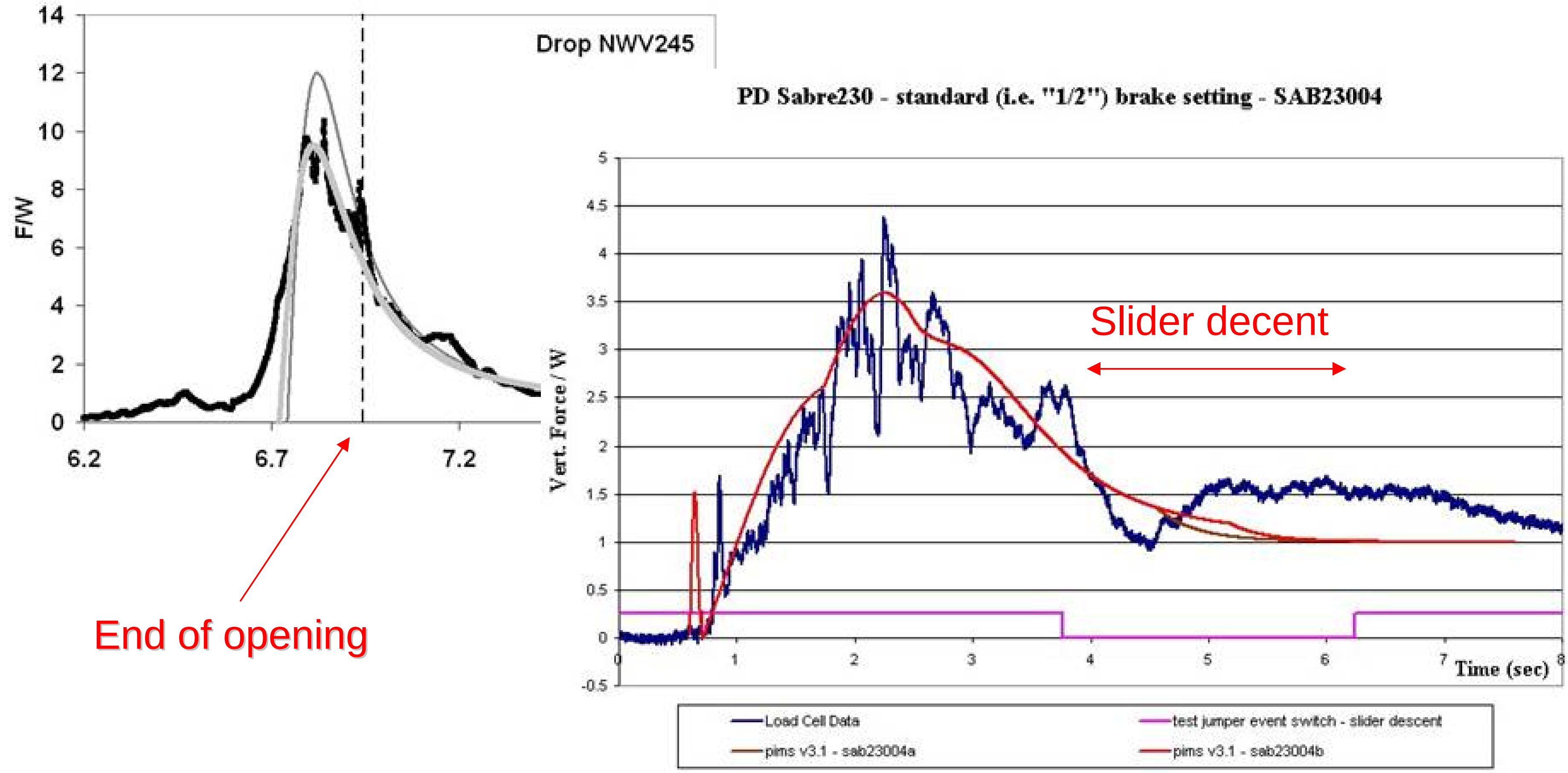

Figure 1. Seven-cell parafoil (200ft^2) opening without a slider (left), versus a nine-cell parafoil (230ft^2) opening with a slider (right). Force expressed in g's. The two openings took place at similar speeds (120 – 150 fps -approx.) and weights (160 lbs approx.). The jagged curves correspond to load cell measurements, and the continuous curves to inflation models created by the authors.

Why do parafoils open hard without opening-control devices?

The opening dynamics of a ram-air wing is controlled by two processes:

- The air entering the cells through the leading edge inlets (i.e. cell inflation)

- The span-wise spreading action of the airstream hitting the bottom skin of the canopy, a process caused by the wing's anhedral and stabilizers (this is the "bottom skin spreading"event mentioned previously)

See figure 2 – next slide

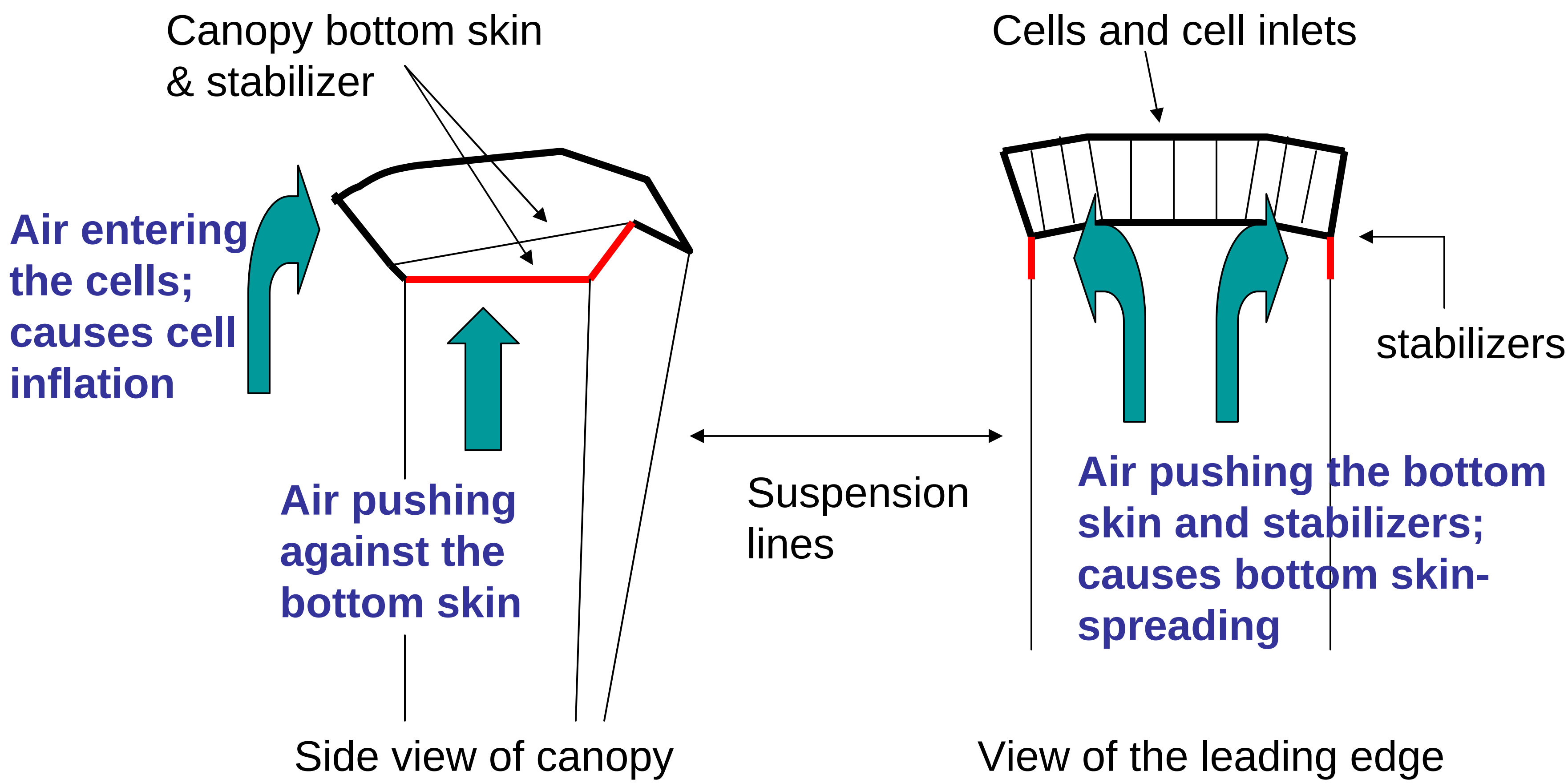

Figure 2. Airstream patterns around an inflating parafoil, at the very beginning of the inflation process (no slider)

But! Cell inflation is a much slower process than bottom-skin spreading.

A canopy opening without a slider will do so via the bottom-skin opening process, and be fully extended before the cells had any chance to fill up with air.

Because of the great swiftness of bottom skin-spreading, the overall canopy opening process generates large forces on the jumper.

The main function of a slider is to suppress bottom skin -spreading, leaving the canopy expansion process exclusively to cell inflation.

Ram-air wings equipped with sliders will open more slowly (and more softly) for the following reasons:
(see figures 3 and 4 – next slide)

- **During the early part of inflation, the oncoming airstream keeps the slider at the very top of the suspension lines, being pushed against the canopy by it's own drag**

- **The presence of the slider at that location provides a constraint that supresses bottom-skin spreading; canopy expansion is now pretty much controlled by cell inflation – a much slower process**

- **As cell inflation continues, there is a build-up of pressure inside the cells, which continues until the wing is pressurized enough to overcome the constraint of the slider; it is at this moment that the slider begins its motion down the suspension lines**

- **By the time of slider-descent, the parachute-jumper system has substancially decelerated so that when the canopy spread fully, the parachute's drag force is much lower**

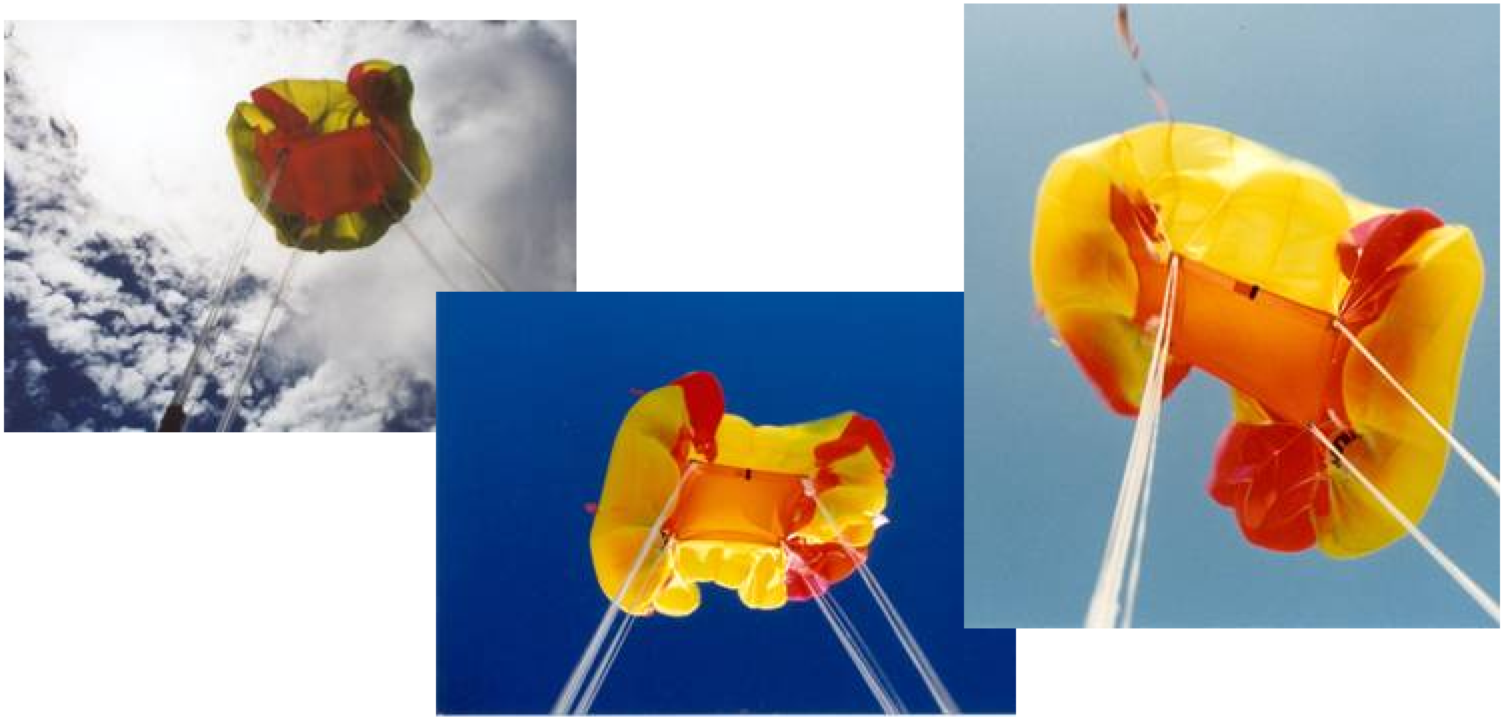

Figure 3. Opening sequence of a slider-reefed parafoil opening in a nominal fashion

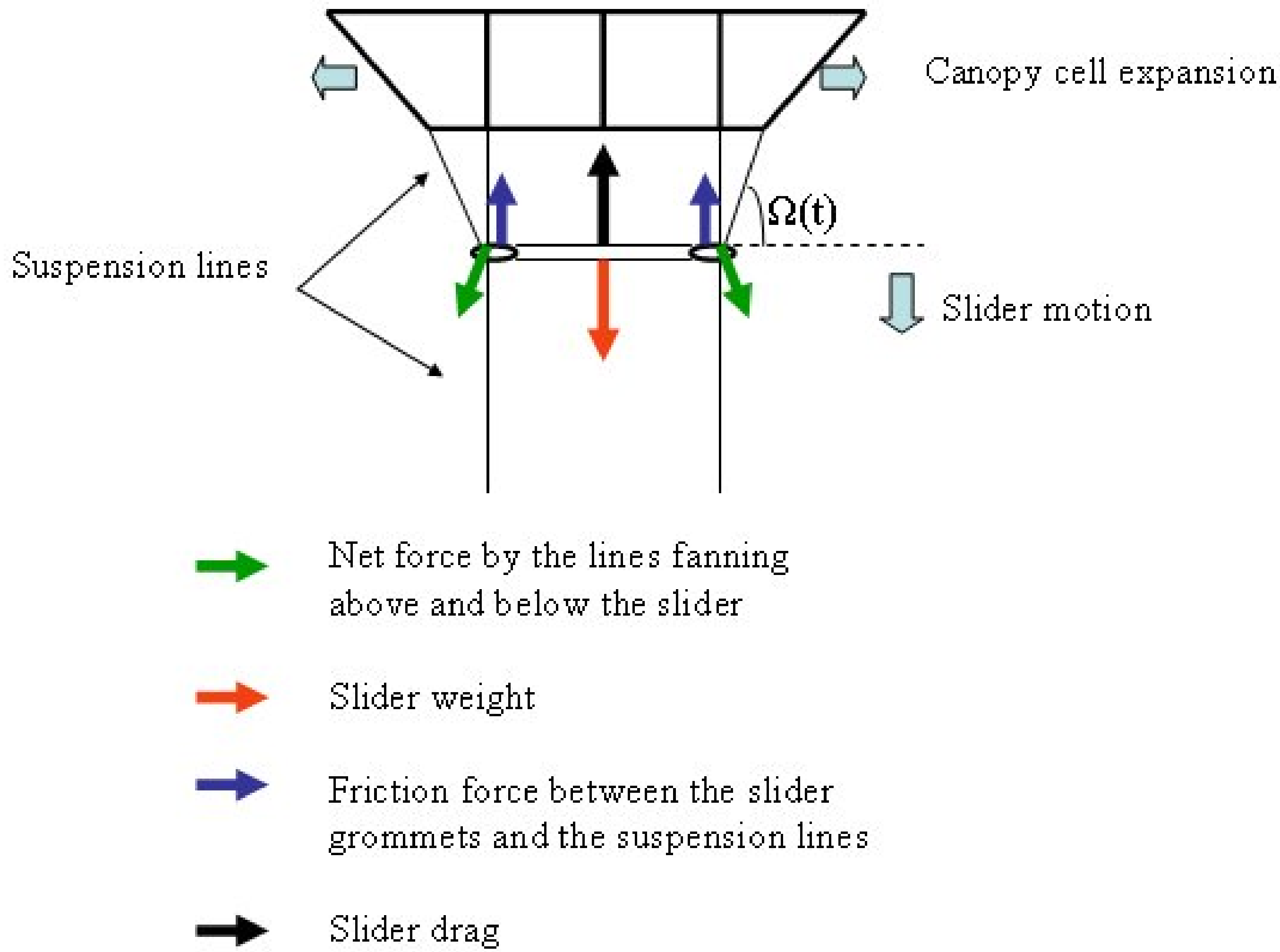

Figure 4. Forces applied on a typical slider, during slider-descent

How is slider drag generated?

- See figure 5 (next slide)

- Note the high-pressure area under the slider, caused by the oncoming airstream

- Note the low-pressure area immediately above the slider, but the under canopy bottom skin, created by the "dead air" between slider and canopy bottom skin (note: there might be actual airflow there – more on this later)

- The difference in (total) pressure between the top and bottom pressure areas is what creates slider-drag

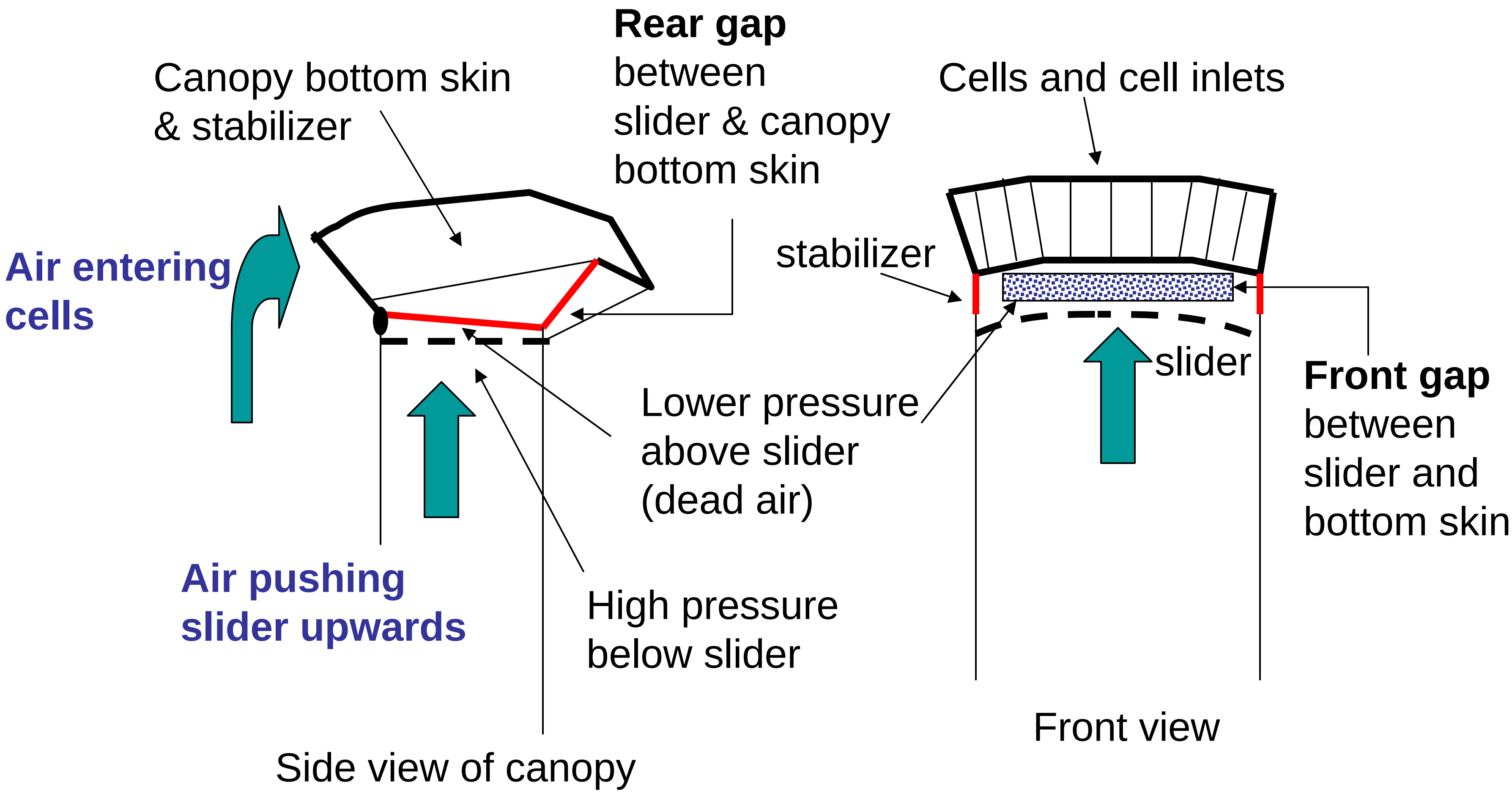

Figure 5. Airstream patterns during nominal openings

2. How can slider drag be cancelled?

SDC is caused by the airstream penetrating the area bewteen the canopy bottom skin and slider surface, <u>from both sides</u> – i.e. through mostly the rear and front gaps[+] see figure 6 (next slide)

High pressure ensues from the collision of both flows, and cancels the effect of the high pressure created by the relative wind hitting the slider from below - hence slider drag cancellation

Without slider-drag, the down-pushing force provided by the lines fanning out of the slider (and generated by span-spreading) is unopposed – see figure 4, above; the slider thus moves downwards very quickly, almost as if the canopy had no slider to begin with

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[+]Note: Penetration may be also facilitated by the down-curvature of the canopy tail corners

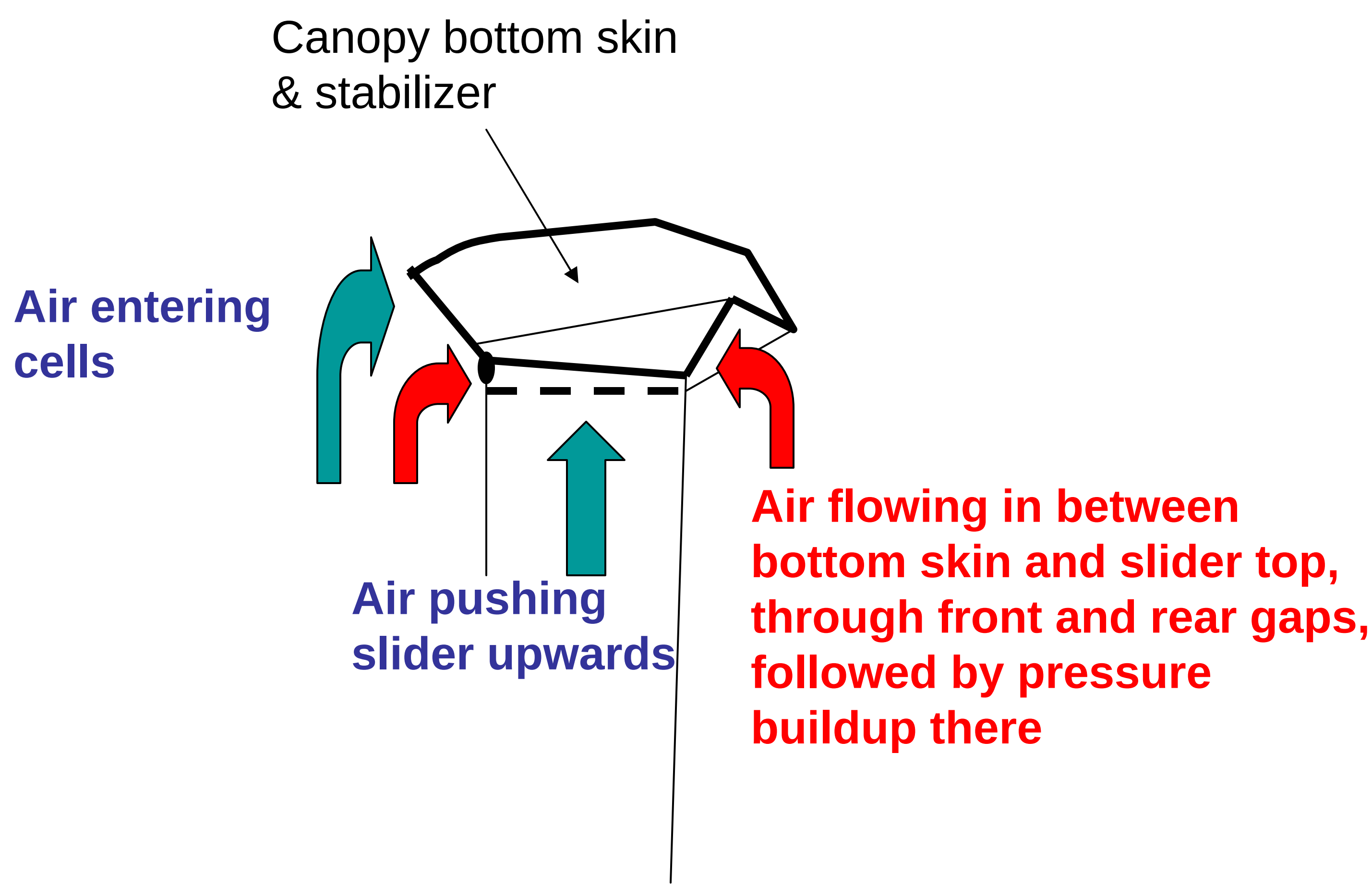

Figure 6. Airstream patterns during abnormal openings, where slider drag is being cancelled out

The “collision” of opposite flows depicted in figure 6 should be a rare event

- **The modern parafoils of today are such that other types of flows between canopy and slider are much likely to occur during *normal* (i.e. “soft”) openings, depending on canopy design specifics:**

  Scenario #1: The “dead” air scenario of figure 5, in which *no* flow occurs – see figure 7

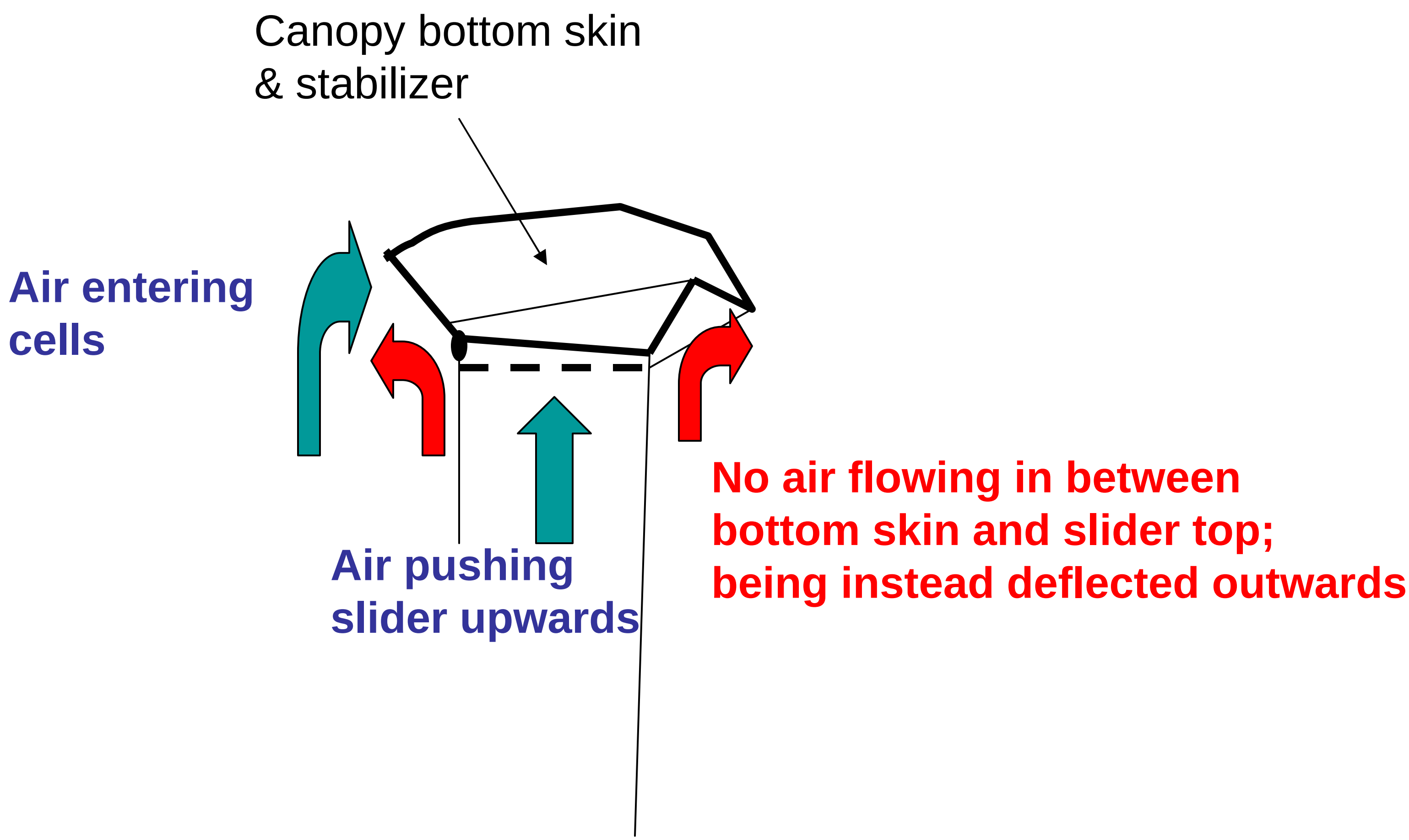

Figure 7. Airstream patterns during normal openings, Scenario #1 – "dead-air" scenario (see also figure 5)

Why is SDC a rare event? Cont'd

Scenario #2: Front-to-rear, one-directional flow – figure 8 (next slide).

>The bottom skin of the wing is *not* horizontal but inclined

>This incline is what gives a wing a good glide during flight; without it the canopy would surge back-and-forth, falling like a leaf

>During openings that generate air motion between the slider and bottom skin (or "through-flow), the incline promotes this flow to occur in one direction only, i.e. <u>from front to rear</u>

>Because the through-flow is perpendicular to the overall relative wind stricking the slider under-surface, the pressure above the slider is lower above its surface than under (remember Bernouilli's principle) - thus leading to non-zero slider drag

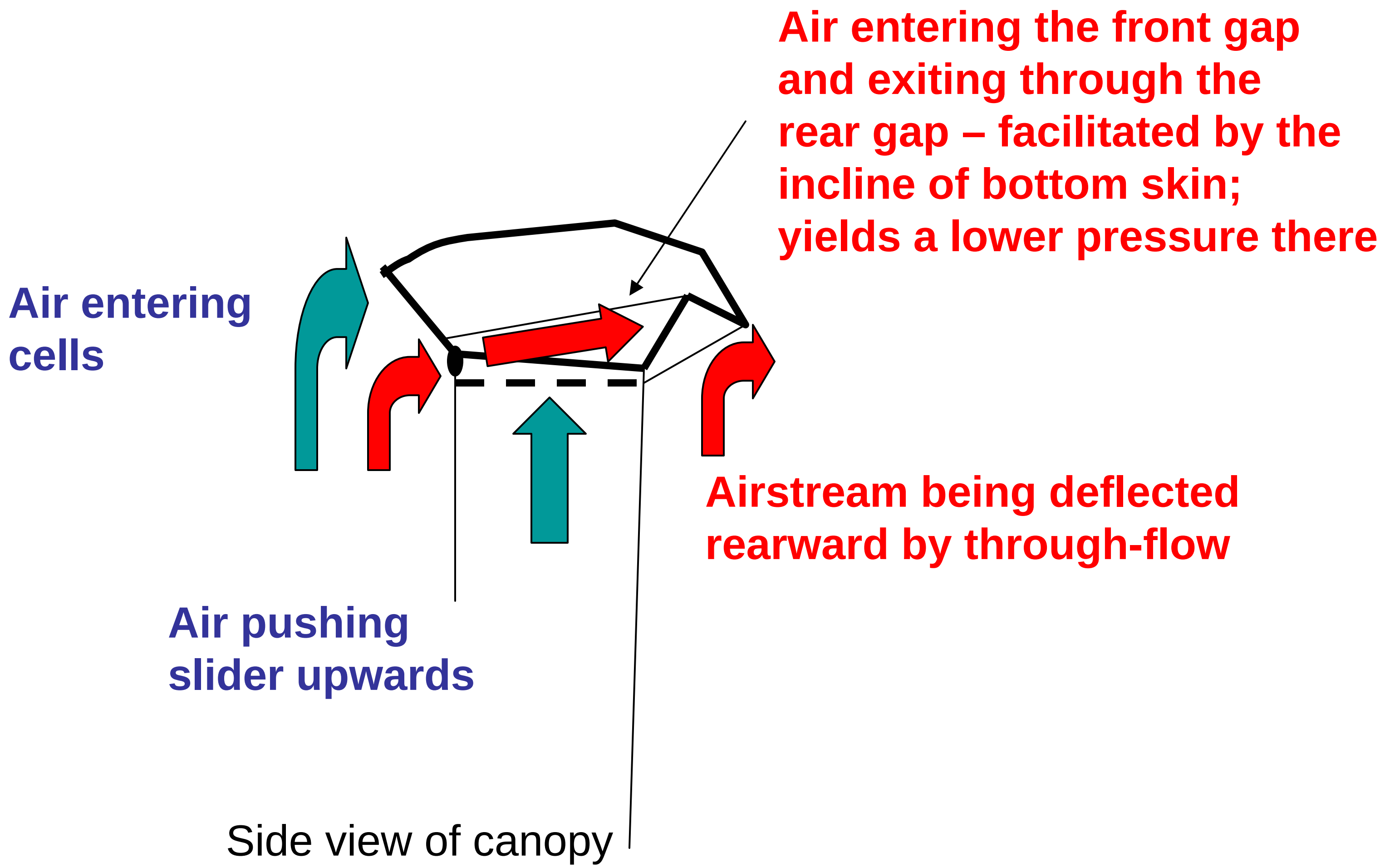

Figure 8. Scenario #2: Airstream patterns between the canopy bottom skin and slider during normal openings

Bottom line: slider drag should exist when the air between canopy bottom skin is either "dead" or through-flowing from front to rear.

Note that the incline could also promote a high pressure area above the slider (and therefore SDC), in the event that the through-flow is mainly rear-to-front

Why should SDC occur at all?

- The inflation dynamics of a ram-air wing is quite sensitive on the manner the canopy unfolds right after extraction from the deployment bag

- Such unfolding is to some extent random, given the randomness associated with how the canopy and slider are folded inside the deployment bag

- Unfolding randomness may also be exacerbated by the turbulence embedded in the airstream hitting the unfolding canopy (including turbulence created by the jumper, btwy)

- …and also by canopy surging motions that may occur right after bag-extraction

- **Flow-through between bottom skin and slider is likely to be initiated or suppressed by such random initial conditions**

3. How to reduce the occurrence of SDC?

How to reduce the lieklyhood of SDC?

Try to eliminate any possibilty for colliding through-flows between the canopy bottom skin and slider surface

Theoretically, one way of doing this could be to use *domed* sliders (figure 9 – next slide):

- They inflate very quickly, i.e. before through-flows above the slider could have been established

- By having fullness, inflated domed sliders would effectively block adverse through-flows from taking place

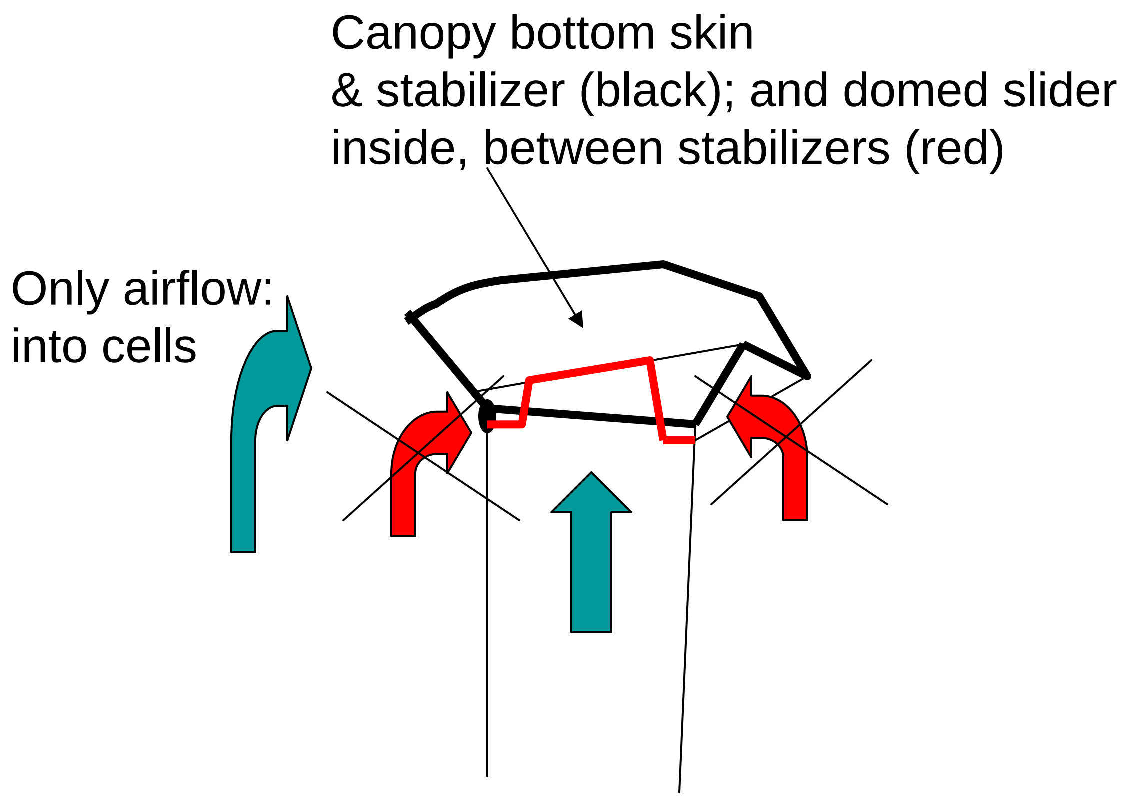

Figure 9. How a domed slider could block adverse through-flow

4. Concluding remarks

- **At the moment SDC is a *hypothesis* which sounds plausible but is in desparate need of experimental evidence**

- **A tip for SDC could be the occurrence of a totally spread-out, but uninflated canopy, captured on video as a jumper looks up at the end of opening**

- **Note again that SDC can exhert its negative effects on its own, or in tandem with slider rebound, or with other negative dynamics that provoke hard openings.**

Please send all questions to:

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