Fall speed under a bag-lock malfunction – a simple calculation

By

J. Potvin and G. Peek

(version 04-03-08)

The question:

What is the fall speed of a skydiver during a bag-lock condition? Is it faster, or slower than the speed sustained during a belly-to-Earth skydive?

The answer:

It might go either way!

Here we describe a simple-minded calculation which shows how this can happen. This calculation is simple enough that it can be easily adapted to a reader's own equipment and weight.

The basic idea

Typically, and during a belly-to-Earth skydive, a jumper freefalls at a speed of about 120mph. Why? It is because his weight is matched exactly by the drag force generated by his body (there is no parachute out here).

As will be shown in the next slides, the drag force depends on the amount of surface area exposed to the wind and on the degree of streamlining of the body. Change those two factor and then you get a different fall rate (at same weight and altitude).

What happens to the fall rate when the jumper is falling under a locked bag and opened pilot chute then? Well, compared to the belly-to-earth case, the exposed area has changed, as well as the body's degree of streamlining; and the deployment bag & pilot chute have added drag too.

So, depending on the specific pilot chute size and design, the fall rate may or my not exceed the belly-to-Earth fall rate!

The formula

The basic formula that determines the fall rate is as follows:

$$weight = drag$$

$$W = \frac{1}{2}\rho\left(S_0 C_{D0}\right)\left(V_{term}\right)^2$$

where

- W =weight; in pounds (American Standard Units (ASU)) or Newtons (metric; not kilos!)
- ρ = air density at fall altitude; in units of slugs/ft^3 (ASU) or kg/m^3 (in metric)
- V_{term} = fall rate, or "terminal speed"; in units of ft/sec (ASU) or m/sec (metric)
- (S_0 C_{D0}) = drag area of the body; in units of ft^2 (ASU) or m^2 (metric)

What is this drag area concept?

The drag area

It is based on the product of the drag coefficient C_{D0} of the body, and of its reference surface area S_0.

Drag coefficient:

The value of drag coefficient is determined mostly by how streamlined a body is, front and aft w/r to the direction of the relative wind: the more streamlined, the lower the C_{D0}. A flat plate facing the wind (like a skydiver in a belly-to-Earth attitude) has $C_{D0} \sim 1.0$; a car has $C_{D0} \sim 0.2$ –to- 0.3 and a Cessna 182 (moving forward) has $C_{D0} \sim 0.03$. The value of C_{D0} is the same in both ASU and metric units.

The drag area (cont'd)

Nominal reference area:

<u>For flat plates, cups, human body, etc.:</u> The value of S_0 is equal to the surface area of the object, projected forward towards the (relative) wind.

<u>For parachutes:</u> S_0 is the so-called nominal surface area:

S_0 = span x chord (ram-air canopies & parafoils with NO forward speed)

S_0 = total surface area of a canopy, including area of vents and slots (round canopies, with or w/o vents). With a canopy made with a flat circular piece of cloth:

$S_0 = \pi (D_0/2)^2$ where D_0 = diameter of the circle

IMPORTANT NOTE: the value of C_{D0} is directly related to how one defines the nominal reference area! Change how S_0 is defined and C_{D0} changes too, but in a way that keeps S_0C_{D0} the same.

Back to the formula of slide #4:

The equation shows that the heavier one is, the faster the fall speed. Other factors that increase the fall speed are:

- higher fall altitude (since the air density "ρ" decreases with altitude)
- less streamlining (as C_{D0} is greater)
- greater body surface area (as S_0 is greater)

Using the following data for a typical guy <u>falling belley-to-Earth</u> at 120mph (true airspeed) at 4500ft MSL§, the formula gives a drag area $S_0C_{D0} = 6.2\ ft^2$.

What about the fall rate under a bag-lock then? What is V_{term} in this case?

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§For those who want to do the math, we used W = 200lbs, $\rho = 0.0021\ sl/ft^3$ and $V_{term} = 176ft/sec$

Under a bag lock, a jumper…

- falls toe-first
- “hangs” under the deployed risers, suspension lines
- “hangs” under the deployed and opened pilot chute

In this case the force balance equation of slide #4 is changed as follows

$$W = \frac{1}{2}\rho\left(S_0 C_{D0}\big|_{body} + S_0 C_{D0}\big|_{bag} + S_0 C_{D0}\big|_{PChute}\right)\left(V_{term}\right)^2$$

Here the drag area of the bag and pilot chute have been added§§. Let us estimate these new terms. Then using those values we’ll re-calculate the fall rate V_{term}.

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§§ **For the purists out there who wonder: yes, we can add those as long as the body, bag and pilot chute are well-separated, ie. are not in each other’s near-wake.**

Drag area estimates

$(S_0\, C_{D0})\big|_{body}$ = drag area of the body only, in a toe-first attitude.
= 3.9 ft^2 -calculated using the formula of slide #4, with V_{term} = 150mph, W =200lbs and ρ = 0.0021 sl/ft^3 (i.e. air density at 4500ft MSL); in other words, using the known speed of a toe-first "normal" skydive with no pilot chute and deployment bag out.

$(S_0\, C_{D0})\big|_{bag}$ = 0 (an approximation)

$(S_0\, C_{D0})\big|_{Pchute}$ = 2.7ft^2 - calculated from C_{D0} = 0.55 (Table 6-6, Knacke's parachute design manual[§§§]), and S_0 = 4.9ft^2, for 30in (diameter) pilot chute.

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§§§ T. W. Knacke, "Parachute Recovery Systems Design Manual"; Para Publishing (Santa Barbara, CA 1992).

The total drag area under bag-lock then becomes :

$$S_0 C_{D0}\big|_{body} + S_0 C_{D0}\big|_{bag} + S_0 C_{D0}\big|_{PChute} = 3.9 + 0 + 2.7\,ft^2 = 6.6\,ft^2$$

…in comparison with the belly-to-Earth value of $S_0 C_{D0} = 6.2\ ft^2$.

At the same altitude and with the same weight, this shows that under a bag-lock condition, the jumper would fall at a slighlty reduced speed, i.e. V_{term} = 170fps, versus 176fps for belly-to-Earth.

With those two drag areas being so close, however, one can see that the fall rate could actually be faster if a smaller diameter pilot chute was being used; or with a 200lbs- very tall and skinny guy falling toe-first with $(S_0 C_{D0})\big|_{body} \sim 2.0$ to $3.0 ft^2$ instead; or with a pilot chute that has a smaller C_{D0} .

So, the fall rate under bag-lock could be either larger or greater than the belly-to-Earth fall rate.

Because the specific drag area and streamlining numbers wont be that different within the skydiving population, the fall rate variations among individuals should not be expected to be that large.

Please send all questions to:

potvinj@slu.edu or peek@industrologic.com