



PIFCalc – The Parachute Inflation Force Calculator - Version 1.0
User's manual

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1. Introduction

Welcome to **PIFCalc**, the **parachute inflation force calculator**. This simple Windows-based program is a diagnostic tool that will give an estimate of the maximum drag force (F_{max}) generated during the opening of a parachute. PIFCalc is strictly limited to manned parachuting, a restriction that confines its use to the low-porosity hemispherical parachutes and parafoils that are used by skydivers (the former are also known as “rounds” and the latter known as “squares”). These parachutes may correspond to either the main or the reserve, and be equipped with or without sliders. For reasons to be explained in Sections 4 and 5 below, PIFCalc cannot be used for investigating the opening force sustained by the drogues and pilot chutes used on skydiving equipment.

PIFCalc has been validated using a large database of instrumented test jumps and test drops, of both production and experimental parachutes. In each sample the collected data included video and load cell data (i.e. force data), as well as fall rate measurements. The parachutes that were used included a 35ft-diameter (round) T-10 military parachute, dropped from a helicopter. Also used in the study were several sport parafoils of rectangular and elliptical designs, built with nine cells and slider-reefed, and made with zero-porosity fabric. Considered as well were two slider-reefed government 7-cell rectangular designs made with low-porosity fabric (“F-111”). The squares sampled surface areas ranging from 120ft² to 370ft², and all were tested during manned freefall jumps. Comparing PIFCalc with this experimental data has yielded estimates that consistently came within 50 to 200 lbs of the measured value of F_{max} (i.e. within 5% to 20% of the measured value), with the largest error being caused by the uncertainties in the measurement of the fall rate prior to inflation – an important input as discussed in the next section.

PIFCalc is a diagnostic tool, i.e. a tool that provides answers only *after the actual opening has occurred*. This is because the program uses as input the duration of the entire opening (or “inflation time”). By “*entire opening*” it is meant ***the time elapsed between the bag-extraction of the canopy and its full opening***. For round or square canopies equipped with a slider, this definition includes both the slider-up phase (also known as “snivel”) and the slider-descent phase. Defined as such, *inflation time* is a number that can be easily obtained by timing the video of the opening with a stopwatch.

As the user will see, PIFCalc uses very few of the many important construction parameters that characterize a canopy and its slider (if a slider is being used). Such characteristics do enter into the calculation, but only indirectly through the actual value of the inflation time. So, to emphasize again this point: PIFCalc is a diagnostic tool, not a design tool.

We envision PIFCalc as being useful to skydivers wondering how hard their canopy opens, especially after hard openings. Test jumpers using rigs that are not equipped with load cells should find this tool equally useful. Finally, the user should be aware that PIFCalc computes the maximum force generated at any time during the opening, i.e. during the combined snatch, snivel and slider descent phases.

2. How to Run PIFCalc?

2.1 Four easy steps

Running PIFCalc is quite easy and consists in the following basic steps:

STEP 0 – Software installation

The program is contained in an executable file named PIFCALC.exe. This file may be located in any Windows directory. No input files are necessary and no output file will be generated.

STEP 1 - Input

The user is to choose a few options and enter a few input data:

- *Choice of unit system, namely between American Standard Units (or ASU) and Metric*
- *Choice of canopy shape (“rounds” vs. squares”)*
- *Specification of freefall speed at the moment of parachute deployment (see notes 1 and 2 below)*
- *Specification of the “size” of the canopy (see note 3)*
- *Specification of the “Mean Sea Level”-altitude at deployment*
- *Specification of the parachutist’s weight (with gear; see note 4)*
- *Specification of the duration of the inflation sequence (using video and a stopwatch, either air-to-air or ground-to-air – see note 5)*

STEP 2 - Calculation

PIFcalc computes the maximum force when the *Calculate* button is clicked. The resulting number can be found on the lower right corner of the window. This calculated force is expressed in pounds (ASU) or Newtons (metric). Note that dividing the force by the input weight gives the maximum force in “g's”. Note also that the *Calculate* button must be clicked whenever the input parameters or options have been changed; otherwise, the calculation will not be completed and the new force will not appear in the output window.

Finally, remember that the correct answer must always be positive; in other words, getting a negative force is an indication that either the inputs are wrong, or the program is being used outside its range of validity. More on this last point in Section 4.

STEP 3 – Print a record of the calculation

Pressing the *Print* button gives the user a written record of the calculation, showing the chosen options, input values and resulting force.

2.2 Examples

Figure 1 shows one example computation, carried out in the American Standard Unit system and involving a square canopy built with a 20ft-span and 10ft-chord. This parachute is being deployed at 2000 ft MSL, after a freefall at 158.7 ft/sec. Here the total weight is 200 lbs and the canopy opens in 2.0 seconds. Under such conditions the estimated maximum force is at 1201.0 lbs. Note that this example is the *Default calculation* which always begins a PIFCalc session.

Figure 2 shows that same parachute system, but investigated in a metric world - i.e. with 6.1m-span, 3.0m-chord, 890 Newtons-weight, 2 seconds-time, 609.7m-deployment altitude and 48.5 m/sec initial fall rate. The result is an estimated maximum force of 5357.3 Newtons.

The screenshot shows the PIFCALC version 1.0 Parachute Inflation Force Calculation program interface. The window title is "PIFCALC version 1.0 Parachute Inflation Force Calculation program". The interface is divided into several sections:

- Units:** "American standard units" is selected.
- Parachute dimensions:** "Parafoil (square)" is selected. "Wing span (feet or meters)" is 20.0, "Average wing chord (feet or meters)" is 10.0, and "Rated (nominal) diameter (feet or meters)" is 26.0.
- Other inputs:** "Weight (pounds or Newtons)" is 200.0, "Inflation time (seconds)" is 2.0, and "MSL deployment altitude (feet or meters)" is 2000.
- Deployment speed:** "Measured airspeed:" is selected. "True airspeed (TAS) (feet per second or meters per second)" is 158.76. "Pre-selected typical airspeeds (sea level adjusted):" includes options for Very fast, Fast, Nominal, Slow, and Very slow.
- Buttons:** "Calculate", "Print", and "Help".
- Output:** "Maximum force sustained (pounds or Newtons): 1201.005".

Figure 1 The *Default* case which begins every PIFCalc session.

The screenshot shows the PIFCALC version 1.0 Parachute Inflation Force Calculation program interface. The window title is "PIFCALC version 1.0 Parachute Inflation Force Calculation program". The interface is divided into several sections:

- Units:** "Metric units" is selected.
- Parachute dimensions:** "Parafoil (square)" is selected. "Wing span (feet or meters)" is 6.09, "Average wing chord (feet or meters)" is 3.05, and "Rated (nominal) diameter (feet or meters)" is 26.0.
- Other inputs:** "Weight (pounds or Newtons)" is 890, "Inflation time (seconds)" is 2.0, and "MSL deployment altitude (feet or meters)" is 610.
- Deployment speed:** "Measured airspeed:" is selected. "True airspeed (TAS) (feet per second or meters per second)" is 48.32. "Pre-selected typical airspeeds (sea level adjusted):" includes options for Very fast, Fast, Nominal, Slow, and Very slow.
- Buttons:** "Calculate", "Print", and "Help".
- Output:** "Maximum force sustained (pounds or Newtons): 5337.343".

Figure 2 Same as *Default* case but expressed in metric units.

3. Notes about the inputs

Note 1 – measured freefall speed at deployment

In principle PIFCalc needs the freefall speed at the moment of canopy extraction from its deployment bag. This input is usually not available to skydivers. However, the fall rate at the moment of deployment, as measured by various electronic altimeters, should be pretty close to that value. Please use either feet-per-second (ASU) or meters-per-second (Metric). Note that when using an electronic altimeter to get the pre-inflation fall rate, one has to know whether the device gives the true airspeed or the sea-level equivalent airspeed. Moreover, the user should be aware of whether the altimeter gives the *average fall speed* over the entire skydive or not, a number which may be substantially different from that of the fall rate just prior to inflation. In such cases, downloading the altimeter data into a computer for analysis may be one way to find out; but this may not be the only way as explained next.

Note 2 – pre-selected freefall speed at deployment

In case the user does not have access to an electronic altimeter or to altimeter data, he/she can choose one of the pre-selected fall rate values that are supplied by PIFCalc. This is done by clicking the *Pre-selected airspeeds* radio-buttons on the right side of the window. These are typical of belly-to-Earth skydiving, as measured by Gary Peek in his barograph study of freefall. For more details on the study, see Gary's article at <http://www.pcprg.com/baro.htm>. The pre-selected values listed in PIFCalc came from Table 1 below. Note that these pre-selected values should also

Fall rate (mph; Sea Level adjusted)	Type of dive & comments
102	camera suit (Garry Carter data)
104	"slow" Strong Tandem
104	very slow face-to-earth formations
108	"average" Strong Tandem
108	overall average face-to-earth formation skydiving (Garry Carter and barographic data)
110	"fast" Strong Tandem
110-115	"fast" recreational face-to-earth formation skydiving
114	competition team face-to-earth formation skydiving (Garry Carter data)
114-120	"fast fallers" in face-to-earth formation skydiving
118-122	Sit flying in a laid back or relaxed position with a standard design sit-flying suit
125-135	sit-flying in a straight-backed sitting position with a standard design sit suit
125-130	skysurfing with normal wing sit-flying suits
150	standing up in a sit-flying suit
125-160	head down flying

Table 1. Results from Peek's study of skydiving fall rates.

apply to head-down skydiving, or to any other type of skydiving for that matter, since one is always supposed to be in a stable, belly-to-Earth attitude prior to deployment. If parachute opening occurred while in a head-down attitude, the user can always enter a somewhat higher airspeed value in the *measured airspeed* entry box (expressed as true airspeed).

Note 3 - canopy dimensions

If jumping with a square, the user must enter the span length and chord length of the canopy. In case the canopy is of an elliptical type, the average chord is used instead as chord-input data. If jumping with a round canopy, the user enters the rated diameter of the canopy.

Note 4 – Units of weight in the Metric system

Users living in the metric world are reminded that PIFCalc cannot use the value of their weight expressed in “kilos”. Rather, they must multiply such *kilos* by 9.81 and use the result as the weight input.

Note 5 - inflation time

Inflation time is defined as the time elapsed between bag-extraction of the canopy and the moment of its full extension - a number that will usually be obtained from the video of the opening (either air-to-air or ground-to-air). Be aware that parachutists using a helmet-mounted camera to record the opening of their own parachute will probably miss the bag-extraction event. The recorded inflation time will thus be somewhat shorter than the true opening time, an error that will lead to *higher* values of the maximum force. Freefalling videographers filming the opening of another canopy, for example during a tandem skydive, will be able to capture the entire opening.

Note that, besides being sensitive to the details of a parachute’s design, the inflation time will also be quite sensitive on how opened a parafoil’s inlets are (or a round parachute’s mouth is) at the very beginning of inflation, a factor that may change substantially on a jump-to-jump basis. Varying initial inlet/mouth opening is quite random, given the limpness of the canopy at the beginning of the inflation process. In other words: canopy design determines an *average* inflation time at a given suspended weight and freefall speed, while the randomness associated with initial canopy limpness not only determines the *actual* opening time, but also *how far* from the average value it can be.

4. Warning - restrictions

This program will give reasonable estimates, regardless of whether the opening was fast or slow, or was malfunctioning. But the user must be aware that PIFCalc has important restrictions and limitations:

4.1 Restriction to manned parachuting

This computer program is strictly limited to the parachutes used in manned parachuting. This excludes the parachutes used in other aerospace applications, such as cargo chutes, brake chutes

and drogues. In particular, PIFCalc cannot handle the cases involving ringslots and other ribbon parachute types, cruciform parachutes (used in drag racing, for example), and disk-gap-band parachutes (used on spacecraft).

4.2 Restriction to Earth-bound parachuting

The use of PIFCalc is restricted to parachuting on Earth because the program uses explicitly the value of the gravitational acceleration constant g as measured near the surface of the Earth.

4.3 Exclusion of extreme deployment altitudes

PIFCalc uses the so-called Standard Atmosphere Model to extract the value of air density from the knowledge of deployment altitude. The formula used for this calculation is restricted to deployment altitudes below 36,089 feet (MSL), or 11,003 meters (MSL).

4.4 Inaccuracies for the case of hop'n pop jumps

PIFCalc works best for openings that happen along the vertical, i.e. after a long-enough freefall. Thus the program is not as accurate for the so-called *hop'n pop* jumps (also known as *clear-and-pull* jumps), which usually happen along a ballistic trajectory. Moreover, the jumper's airspeed at the moment of parachute opening is not equal to that obtained from electronic altimeters, as they measure vertical fall rates only. But a reasonable estimate can be obtained for jumps that involve deployment right after clearing the aircraft. In that case the aircraft airspeed can be substituted for the input freefall speed (again in feet-per-second or meters-per-second); moreover, the value obtained from PIFCalc must be reduced by $2W$ (i.e. twice the input weight). The actual value of the maximum force should be somewhere in between that (manually) corrected value and the original (i.e. uncorrected) value.

4.5 Warning Error - Low Initial Speed

PIFCalc works best when the speed at the beginning of inflation is greater than the descent speed of the jumper under the inflated canopy (a number calculated by PIFCalc). This condition is easily met by all aircraft-borne freefall jumps and by most BASE jumps. But in cases where this condition is not met, PIFCalc will post a *Warning Error* window to let the user know that the calculation may be inaccurate.

4.6 Warning Error – Low Mass Ratio

As mentioned earlier, PIFCalc is limited to the main and reserve parachutes used by people. This restriction is connected to what parachute engineers refer to as *mass ratio*. The mass ratio is a rough measure of the air mass that co-decelerates with the canopy during inflation. The formula used by PIFCalc is only valid in cases where such air mass is comparable (in weight) to that of the jumper. This is why PIFCalc will not give a good estimate of the maximum force sustained by drogue chutes and pilot chutes which feature tiny mass ratios. PIFCalc will post another *Warning Error* window to let the user know that the calculation may be inaccurate whenever the mass ratio is smaller than 10% of the jumper's full gear mass. It must be pointed out that canopies with 100ft^2 (10^2 m^2) surface area or less, while being loaded in excess of 2.0 lbs/ft^2 , are getting quite

close to this 10%-mass ratio limit (their mass ratio are at about 30%). Here PIFCalc could be somewhat overestimating their maximum opening force.

5. Technical details

Derivation and assumptions

This opening force calculator is based on a simple formula that is obtained directly from Newton's celebrated formula " $F = ma$ ":

$$F_{\max} = \frac{2WV_i}{gT} \left[1 - \frac{V_{\text{final}}}{V_i} + \frac{gT}{V_i} \right] = \left(\frac{2WV_i}{gT} \left[1 - \frac{V_{\text{final}}}{V_i} \right] \right) + 2W \quad (1)$$

where

W = parachutist's weight, with full gear

g = constant of gravitational acceleration (= 32.17ft/sec² (ASU) = 9.81m/sec² (metric))

V_i = fall rate at the beginning of inflation

V_{final} = fall rate at the end of inflation

T = duration of the inflation sequence

What is interesting about (1) is the fact that it confirms what skydivers have known for a long time: the faster the opening (i.e. the lower the T), the harder the opening. It also shows that increasing the weight also increases the maximum force. Finally, equation (1) suggests, although not as obviously, that the higher the deployment altitude the higher the force (this follows from V_i increasing and T decreasing at higher altitudes).

Equation (1) was derived from what physicists and engineers know as the *Momentum-Impulse Theorem*. Details of this derivation can be found in "*On Opening Shock Factor - Mass Ratio Universality*", by J. Potvin, in an upcoming issue of *Journal of Aircraft* (2006) (copies of the article, in manuscript form, are available on request, at the email addresses listed below). The derivation is quite general and applies to both "rounds" and "squares". To re-assure users puzzled by its applicability to both types of parachutes, let us say simply that in this type of formulation, the specifics of the parachute design and construction has been "bottled into" the value of the inflation time T .

Equation (1) is quite accurate for sport parachuting applications, as long as it is subject to the restrictions discussed in Section 4. These restrictions arise from three assumptions that were made in the derivation of (1) from " $F = ma$ ". These assumptions are as follows:

- Assumption of a *purely vertical fall* during the inflation process:

To see how this assumption enters into the picture, compare (1) with the approximation of " $F = ma$ " corresponding to parachutes opening along a purely horizontal trajectory (like for brake chutes behind aircraft and race cars):

$$F_{\max} = \frac{2WV_i}{gT} \left[1 - \frac{V_{\text{final}}}{V_i} \right] \quad (2)$$

Notice the absence of the $2W$ -term in equation (2). For parachutes opening along trajectories that are ballistic (i.e. a mix of horizontal and vertical motion), the $2W$ -term is multiplied by a constant that is between 0 and 1 (the more vertical, the closer to 1). Thus applying (1) to situations where the parachute-jumper are not falling vertically during inflation will result in an over-estimate of the real value of F_{\max} . For example PIFCalc would provide a value that would be higher by about $0.15 \times (2W)$ for trajectories that are approximately 30° -off the vertical.

- Assumption on the shape of the force evolution on a force-versus-time graph:

This assumption is reflected by the factor of “2” in the “ $2WV_i/gT$ ” -product in (1). This number is related to whether the drag force generated by the opening canopy is spread evenly over time, in which case the factor should be equal to “1”, or is sharply peaked, in which case it should be equal to about “4”. Our database shows that for skydiving canopies, the force evolution finds itself in-between these two extreme, yielding the factor of “2” above. On a jump-to-jump basis this number may vary between 10% to 30% depending on parachute design and construction. Note that the factor becomes equal to 4 (approximately) at low mass ratios - hence the *Low Mass Ratio Warning Error* discussed in Section 4. More details on this factor can be found in the “*On Opening Shock Factor...*”-reference cited earlier.

- Approximating the value of V_{final} :

Here the value of V_{final} is approximated by the speed V_{descent} of the jumper descending under a fully opened canopy (vertical component for squares). V_{descent} depends on W , and also on the air density ρ , canopy surface area S and drag coefficient C_D as calculated by the standard steady-descent formula:

$$V_{\text{descent}} = \sqrt{\frac{2W}{\rho S C_D}}$$

Here the value of C_D is as follows: $C_D = 0.7$ (rounds) or 1.0 (squares). These assumed values exclude from consideration ribbon-type parachutes and high aspect-ratio cruciform parachutes.

Note that this approximation fails miserably at low mass ratios and is also at the origin of the *Low Mass Ratio Warning Error* discussed previously. Moreover, it fails badly when the initial speed V_i is very small: in such a case V_{final} can either be much smaller than V_{descent} or much greater than V_{descent} – hence the *Low Initial Speed Warning Error* window that will pop up in such a case.

Errors on the value of inflation time (T)

Again, equation (1) should be quite accurate provided the calculation is performed within the range of validity of these approximations. Of course, the result can be way –off if the value of the opening time T is erroneous. For example, errors will be introduced if the video of the opening is

missing the bag-extraction sequence. The magnitude of this type of error will depend on how much of the opening has been missed.

In case the user does not have access to video, educated guesses of F_{max} could be obtained using a *range* of opening times that are typical to the type of canopy being used. For sport squares equipped with sliders for example, the authors have seen parachute openings ranging anywhere between 0.5 seconds (illustrating a “line dump” case) and 3.0 seconds (long snivel). Performing several PIFCalc computations using these values (and a few in-between) together with the user’s own weight and canopy dimensions should give a least an idea of what to expect.

6. Contact information

For further questions about PIFCalc, please contact the authors:

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A copy of the PIFCalc executable can be downloaded from www.pcprg.com/research .