Insights into the danger of breakage to sport aviation karabiners

What is the difference between breakage strength and fatigue strength?

The breakage strength specification stamped onto a karabiner relates to a single loading. By repeated alternation from high loading (F_o) and subsequent high load release (F_u) of the karabiner, the breakage strength sinks. Above a certain difference of tensions caused by F_o and F_u damage occurs to the material of the karabiner. When the karabiner is completely load released, $F_u = 0$.

As fatigue strength one referres the upper load (F_o) by which no more damage occurs to the karabiner material. In the field of aviation, the fatigue strength F_o is ascertained by oscillation tests. Thereby the karabiners have to stand up to 5 million loading oscillations without breaking. The fatigue strength should be sufficiantly high to hold frequent occurring oscillations in flight with a maximum permitted hang-in weight. The DHV measured frequent oscillations in paraglider flights with $F_o = 80$ kg with a hang-in weight of 90 kg distributed between two karabiners. It can be assumed that the loading to the karabiner is twice as high when hanggliding.

By karabiners with catch play, the difference between breakage strength and fatigue strength can be abnormally high. The DHV for example determined a breakage strength of 1860 kg and a fatigue strength of only 35 kg (with closed catch) for the Austrialpin Parafly karabiner. A fatigue strength of 35 kg is insufficient in any case. For this reason, verifications of the fatigue strengths of sport aviation karabiners is absolutely essential.

What is the reason for the unusually low fatigue strength of sport aviation karabiners?

Because of the play in the fastening catch, which is present in conventional karabiners due to the design and to manufacturing tolerances, the karabiner catch becomes effectual only when the karabiner bends open (as a result of more or less high loading) to such an extent that the play disappears. Whilst catch play is still present, the karabiner is stressed like an open ring, when the play disappears it is stressed like a closed ring.

By the loading case "open ring" the lever arm of the broad strap support increases the tensions in the karabiner material by loading and by loading release 20-35 times in comparison to the loading case "closed ring". After the catch is loaded (loading case closed ring), the increase of tensions caused by oscillations of the same load augmentation are much lower, due to the henceforth altered load-bearing system. Thus a karabiner with catch play displays different increases and decreases of tension above and below the point of actuation by gravity.

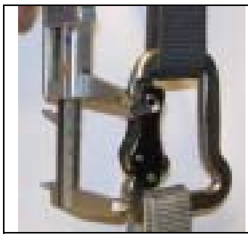
Regarding karabiners with gate play, one has to differentiate between two kinds of fatigue strength: One fatigue strength until the point of actuation by gravity (F_{ou}), and one fatigue strength over the point of actuation by gravity (F_{oo}). The critical oscillation load for the fatigue strength under the point of actuation by gravity is that, by which the peak value of the oscillation loading F_{ou} amounts to the same load F_k necessary for the catch to actuate by gravity. The release loading F_u following such an oscillation, then causes tensions in the karabiner material becoming respectively low. The differences in tension in the karabiner material significant for the fatigue strength reaches a maximum here. A further critical oscillation loading with F_{oo} above the point of actuation by gravity is usually not of any relevance.

Regarding the dynamic load, it can be assumed for the sake of simplicity that the karabiner is safe when the fatigue strength (F_{ou}) – established when the karabiner catch is open – is clearly greater than the load (F_k) necessary to result in the catch becoming actuated by gravity. That however is not the case for the majority of karabiners presently in use.

How high is the loading needed to make the catch become actuated by gravity (no catch play)?

The loading (F_k) required for the actuation by gravity is decisive in establishing the fatigue strength of a karabiner. As the examples show in the table below, there is a wide variety of tolerance even within a particular model of karabiner. F_k must therefore be individually ascertained for each single karabiner in use.

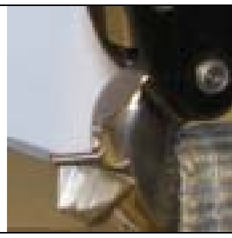
To establish the F_k we gradually loaded and measured the reduction in gate play by increased loading, with several karabiners. When further loading no longer altered the gate play then the point of actuation by gravity had been reached. The loading (F_k) necessary to attain actuation by gravity could in this way be established with an exactness of +/- 2 kg.



The picture shows the test arrangement to determine F_k.

The alignment of the straps is similar to that of the oscillation tests of the DHV.

Dowel pins were attached to the catch of the karabiner in order to measure exactly how much play was present.

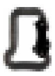
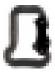
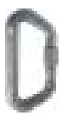


To approximately test the safety of a karabiner every pilot can establish the point of actuation by gravity F_k of his karabiner for himself by measuring the loading required up to the point where the catch can no longer be opened.

In doing so, it is not necessary to measure the amount of gate play. In the case of many karabiner models, the gate play is not visible because the fastener is concealed.

Here you can find practical tips for establishing the point of actuation by gravity.

For example the following values were ascertained (also see test report of the Sincotec test engineering GmbH):

	1	2	3	4	5	6	7	8
	Model	*Batch-identification*	*Catch play of the tested karabiner*	*Measured actuation by gravity* ***F_k*** *at*	*Permanent deformation* ***F_{vo}*** *catch open by approx.*	*Preliminary tested fatigue strength* ***F_{ou}*** *catch open approx.*	*Necessary actuation by gravity* ***$F_{k\,erf}$*** *by* ***F_{ou}: 1.2***	*Fatigue strength catch closed*
	Austrialpin Parafly Alu anodised (1) Paraglider karabiner	-0-0-0-0-4	2,52 mm	147 kg	225 kg	25 kg *	21 kg	not given
	Austrialpin Parafly Alu anodised (2) Paraglider Karbiner	-0-0 0 0 5	0,64 mm	39 kg	225 kg	25 kg *	21 kg	not given
	Austrialpin Parafly Alu anodised (3) Paraglider karabiner	-0-0 0 0 5	0,30 mm	15,5 kg	225 kg	25 kg *	21 kg	**given**
	Austrialpin Powerfly Inox steel (1) Paraglider karabiner	0-0-0-0-0-0 000001	0,65 mm	65,1 kg	250 kg	60 kg ***	50 kg	not given
	Austrialpin Powerfly Inox steel (2) Paraglider karabiner	0-0-0-0-0-0 000001	0,38 mm	39 kg	250 kg	60 kg ***	50 kg	**given**
	Supair Twistlock Alu Paraglider karabiner (1)	not present	0,94 mm	58 kg	380 kg	90 kg ***	75 kg	**given**
	Supair Twistlock Alu Paraglider karabiner (2)	C04	1,45 mm	85,5 kg	380 kg	90 kg ***	75 kg	not given
	Supair Twistlock Steel Paraglider karabiner	001	1,13 mm	86 kg	350 kg	45 kg ***	37,5 kg	not given
	Camp Twistlock Alu Paraglider karabiner KN 20	not present	1,31 mm	77 kg	440 kg	50 kg ***	41 kg	not given
	Austrialpin 3200 Delta Rectangular steel karabiner 12 mm Hangglider karabiner	. . . .	1,15 mm	214 kg	300 kg	160 kg ***	133 kg	not given
	Stubai Super 5000 D-shape for ropes	CE0408	0,37 mm	164 kg	1750 kg	245 kg **	204 kg	**given**

* ascertained by the DHV in oscillation tests with 5 million load alternations
** calcualated from F_{vo}
*** Ascertained by an accredited test institute (ordered by Finsterwalder)

Apart from ascertaining the point of actuation by gravity (F_k) we used the same test arrangement to measure the loading (F_{vo}) necessary to cause a permanent deformation of the karabiner to the extent that the fastening was no longer functional.
As one can assume a linear interrelationship between the fatigue strength established in oscillation tests and the beginning of permanent deformation of a karabiner (which shows that the flow limit is clearly exceeded), one can roughly estimate the probable fatigue strength from F_{vo}.
On this basis, and including a safety reserve of 20 % one is able to specify the load by which actuation by gravity in the catch must be present for the karabiners in the table.
If the point of actuation by gravity (F_k) established in the tests is smaller or of the same size $F_{k\,erf}$ (compare the columns 4 and 7 in the table), then the karabiner has sufficient fatigue strength.

Of the karabiners that were tested, only 2 out of 11 fulfilled this criteria (see table).

Following on for the paragraph "operation loads" (see below), due to its high carrying capacity with an open catch it can be calculated, that the Stubai Super 5000 is fatigue resistant for a hang-in weight of up to 115 kg for the loads frequently occurring during flight, **irrespective of the amount of gate play.**

Why are relatively few cases of fatigue breakage known about in sport aviation?
As has already been worked out in detail, the actuation by gravity by high loading prevents a strong excessive strain of the karabiner material. By less excessive strain through oscillating loads during usage, an oscillation breakage is not certain to occur, but the possibility exists.
The ICE trains in Germany travelled on wheels that were not fatigue endurable for years before a wheel rim broke near Eschede causing a catastrophe. The broken wheel rim had not even been in use for an especially long period of time.

It can also be assumed that not all cases of oscillation breakage have made the news, as personal injury has not yet occurred. For the most part, the karabiners broke during launch. The reason for this is that the oscillation loading in flight leads first to a crack in the karabiner. Due to this crack, the catch becomes actuated by gravity and the fluctuations in tension in the karabiner material are reduced to such an extent that the karabiner usually does not fracture completely. However, the loading capacity of a cracked karabiner with closed fastener is more or less a matter of chance. In case that a crack appears, an adequate carrying capacity has to be count for lost. In any case, the failure of a partially broken karabiner as a result of metal fatigue cannot however be described as an overload breakage.

Are limitations to the service life a solution by insufficient fatigue strength?

Exceeding the fatigue strength by frequent occurring oscillation loads during flight, is not acceptable. Breakage (even when fairly improbable) can occur after a relatively low number of oscillations without prior warning. Hence a formula does not exist for the limitation of the service life when the fatigue strength is exceeded. Quite the opposite: In all technical fields a safety reserve is planned. These reserves are necessary in order to make allowance for fluctuations in the strength of the material and the product. In civil engineering a safety margin of 2.5 times for fatigue strength is demanded wherever loss of life is threatened by the failure of a building component. By the fatigue tests for aircraft construction, a safety reserve of 1.75 is required for load-bearing construction elements.

In fact there are no regulations for karabiners used in the field of aviation sports, however the regulations from similar technical fields must be adopted analogously. The service life limitation of 500 hours of flight for the Austialpin and Supair aluminium karabiners, and of 1500 hours of flight for the Austialpin steel karabiner can certainly not be deduced from the oscillation load tests and from the amount and frequency of the loading in flight established by the DHV. The fatigue strength is critically dependant on the point of actuation by gravity, which has not been defined for the karabiners until now. By oscillation tests made by the DHV, a Parafly was subjected to a loading of F_{ou} 70 kg. It broke after only 33400 load alternations. By Parafly karabiners we established points of actuation by gravity F_k of up to 147 kg! As the latent danger of breakage cannot be limited, limitations of the service life due to inadequate fatigue strength are not acceptable. An airsport karabiner which is not fatigue endurable is not airworthy.

When do limitations to the service life make sense ?

The service life is limited if the airworthiness can no longer be guaranteed after a certain period of use, due to wear and tear, the danger of corrosion etc. Insufficient fatigue strength is not wear and tear however, but rather an avoidable danger that exists as of the first usage. By insufficient fatigue strength, every oscillation over a certain level occurring during normal flight, can result in damage to the karabiner material. This deterioration can add up and lead to breakage within a short time.
Even when the service life is limited for reasons other than insufficient fatigue strength, the service life specified in operation hours only makes sense when operating-hour counters are present or the maintenance of a flight log book is mandatory. As this does not apply to the field of sport aviation, the service life for a karabiner must be stipulated in a time span beginning from the date of purchase, rather than in hours of flight. Regarding product liability, the specification of a service life in hours is irrelevant in the event of damage, as according to the current legal position, the harness manufacturer is liable if the hours of usage of the karabiner cannot be proven.

Does the problem of material fatigue affect other construction elements used in sport aviation?

Generally speaking, extra tests for the fatigue strength of construction parts are unnecessary, since by the prescribed airworthiness tests, a multiple of the loading arising under normal flight conditions are tested. The frequently occurring operative loadings, under normal flight conditions are so low in comparison to the tested loading, that they are irrelevant for the fatigue strength. If the certification tests for the harnesses had been carried out with karabiners with open catches, then their insufficient strength would have been recognised immediately, and eliminated by altering the construction.

Which operating loads are of consequence for aviation sport karabiners?

The measurements by the DHV with a hang-in weight of 90 kg on the paraglider show, that when launching, both karabiners are loaded from 0 up to approx. 70 kg. When thermaling, alternating loads of between 30 kg and 60 kg are typical. When turning, alternating loads between F_u = 25 kg and F_o = 80 kg arise frequently. The top values when spiralling lie between F_u = 20 kg and F_o = 120 kg. The load alternations occur within split seconds in some cases.

The measured values are dependant upon the weight of the pilot, and have to be converted for F_o to the maximum certifiable pilot weight, and for F_u to the minimum certifiable pilot weight. One must assume twice the value for hangglider karabiners. That means: The fatigue strength F_{ou} of a karabiner with an open catch must be higher than its point of actuation by gravity of the catch by a safety factor of at least 1.2 and the fatigue strength F_{oo} of the karabiner when actuated by gravity must be higher than the frequent operating load multiplied by a safety factor of 1.2.

Calculated in each case with a hang-in weight 120 kg this results in a required fatigue strength $F_{oo\ erf}$ for paraglider karabiners that are actuated by gravity of 1.33 x (F_o) 80 x 1.2 = 128 kg. For hangglider karabiners that are actuated by gravity, a fatigue strength $F_{oo\ erf}$ of 256 kg would be required, based upon the frequent loadings occurring when turning.

Are lighter pilots less endangered than heavy pilots?

Assuming that the fastening catch of an Austialpin Parafly paragliding karabiner becomes actuated by gravity by a loading of 50 kg and the fatigue strength of the karabiner with open catch amounts to 25 Kg.
Pilots with respective hang-in weights of 60 kg and 120 kg are flying. In accordance with the frequent operating loads when turning in flight, established by the DHV, the karabiners of the respective pilots with 60 kg and 120 kg experience peak values of 16.6 kg and 33.3 kg by loading release, and peak values of 53.3 kg and 106.7 kg by loading.

The dynamic loading of the karabiners can then be demonstrated as follows:

Austrialpin Parafly, pilot 60 kg point of actuation by gravity 50 kg:

Dynamic rate before actuation by gravity	50 - 16.6 = 33.4 kg
after actuation by gravity (reduced by a factor of 20)	(53.3 - 50) / 20 = 0.2 kg
	33.6 kg

The range of oscillations of 33.6 kg by the light pilot is higher than the fatigue strength of 25 kg.

Austrialpin Parafly, pilot 120 kg point of actuation by gravity 50 kg:

Dynamic rate before actuation by gravity	50 - 33.3 = 16.7 kg
after actuation by gravity (reduced by a factor of 20)	(106.7 - 50) / 20 = 2.8 kg
	19.5 kg

The range of oscillations of 19.5 kg by the heavy pilot is lower than the fatigue strength of 25 kg.

The example shows that under certain circumstances, lighter pilots produce more acute dynamic stresses to the karabiner than heavy pilots.

Are steel karabiners safer than aluminium karabiners?

Whether or not a karabiner is safe depends solely on its construction. Generally speaking steel has a higher fatigue strength than aluminium. The fatigue strength depends however on a multiple of factors. Contrary to the accepted opinion, tougher and more malleable steel breaks (as a result of alternation loading) in just as brittle a manner as less malleable materials (without deformation in the area of breakage and without any prior warning). In how far the tensions due to oscillation loading approach the deformation limit of the material, is decisive. High strength aluminium alloys have a similar strength to common unhardened Inox steel. This is why the difference in fatigue strength is minimal. By the manufacture of karabiners from bent rods, strong reset energies arise in the bends, causing traction tensions on the inner sides of these bends. These are in addition to the tensions arising during usage. Tempering can eradicate these tensions to a greater or lesser extent. In relation to their weight, high quality aluminium alloys are stronger than those of steel, this being the reason why primarily aluminium alloys are utilised in the aviation industry.

Aluminium karabiners with catch play have the advantage over steel karabiners with catch play, that given the same amount of play (and provided that the karabiner dimensions are similar), the aluminium karabiner has a much lower point of actuation by gravity. The reason for this being that aluminium is approximately three times less stiff in comparison to steel.

Were the breakages of the anodised Parafly karabiners in the Czech republic and Brazil overload breakages?

Find more information here and draw your own conclusions.

Conclusions:

- In the range of catch play, the karabiner with closed catch is stressed just the same as if the catch was open. The tensions in the karabiner material which are decisive for the fatigue strength are then multiplied by 20-35 times.
- When the catch of the karabiner exhibits no actuation by gravity the danger of a continuous oscillation breakage exists, when the actuation by gravity in the fastening catch arises by a loading (F_k) that is greater than the continuous oscillation strength (reduced by 20%) F_{ou} of the karabiner, that was ascertained with open catch in the test arrangement of the DHV.
- An airsport karabiner which is not fatigue endurable is not airworthy.
- The risk of material fatigue to the karabiner within the play of the catch affects light and heavy pilots in the same manner.
- Every pilot should establish the point of actuation by gravity F_k himself by gradually weighting his karabiner and testing the loading by which the catch can only just no longer be moved. A tip for carrying out this test practically can be found here.
- The fatigue strength F_{ou} of various aluminium and steel karabiners with open catch was determined by us to be 25-90 kg. The karabiner manufacturers and/or the DHV are called upon to establish the exact values F_{ou} of the karabiners (catch open in the test configuration of the DHV) **and to publish them.**
- After every flight, karabiners with catch play must be inspected for cracks in the bend of the opposite side to the catch.
  The picture on the right shown such cracks. In case that a crack appears, an adequate carrying capacity has to be count for lost.
- The manufacturers of karabiners with catch play should ascertain the point of actuation by gravity by ordering back the karabiners to test them.
- As long as there is any doubt regarding the fatigue strength of the karabiner in use, we recommend attaching an addidional safety feature.
- The selling of karabiners that are not fatigue endurable should be stopped immediately.