Spider silk as mechanical lifeline

SIR — Here I look at the relationship between the mechanical properties of silk drag-lines and a spider's weight, to explain the measured values of the mechanical strength of drag-lines. Spider silks have been studied from the points of view of mechanical strength[1-3], strain energy[4], physico-chemical[5], thermal[6] and optical[7] properties, and ageing[8]. There have been many estimates of breaking strength, elastic modulus[9,10] and elongation from stress–strain curves. Mechanical strength has been explained at the molecular level and examined from the point of view of molecular orientation[11,12].

Drag-lines secreted from the spider's body are a tool for the animal to move, fall from trees, capture insects and build orb-webs, as well as to support her weight and keep her alive. It is well known that drag-lines are a lifeline for spiders, as these animals are often surrounded by danger. The mechanical strength of drag-lines may be related to the spider's weight because spiders hang from them, but, to my knowledge, there have been no reports detailing this relationship. I therefore considered the mechanical strength of the drag-line as a 'safety coefficient'. The spider's 400-million-year evolution should have allowed the mechanical properties of drag-lines to become maximally efficient.

It is important to know whether measured values of elastic-limit strength and breaking strength are meaningful as safety coefficients. A clear relationship between mechanical strength and spider weight would provide a basis for the safety coefficient — a measure of security, equivalent to that used in structures such as lifts, string, rope, aeroplanes, bridges and fibres.

The silk threads used in the present study were drag-lines secreted by female *Nephila clavata* when falling from a wooden bar. I carefully measured stress–strain curves for the drag-lines using a Tensilon. I defined the elastic-limit strength as the stress at which the stress–strain behaviour changes from linear to nonlinear, and the breaking strength as the stress at the breaking point. Figure 1*a* shows the stress–strain curve for the drag-line of a spider with a weight of 4.6×10^{-3} N, measured at a stretching velocity of 3.3×10^{-4} m s^{-1}. I repeated the measurements four times for each sample, and averaged the data. All measurements were carried out at 25 °C and 60% relative humidity.

I plotted the elastic-limit strengths at a stretching velocity of 3.3×10^{-4} m s^{-1} for *N. clavata* drag-lines against the spider's weight W in Fig. 1*b*. The elastic-limit strength increases linearly with increasing spider weight, with a slope of about 2. The stress–strain curve of drag-lines enters a nonlinear region when the stress exceeds about twice the spider's weight. This means that it is safe to use a single drag-line to carry her weight and a prey item, as long as the total stress does not exceed twice her weight. A drag-line from the spider's body consists of double filaments[13]. Even when one filament is broken, the other will easily support her weight. The spider's weight will correspond to the elastic strength for the single filament. Thus, elastic-limit strength gives a minimum safety and a maximum efficiency for supporting the spider's weight. Figure 1*b* also shows the breaking strength of *N. clavata* drag-lines plotted against weight. The breaking strength increases linearly with increasing spider weight with a slope of about 6. Thus, drag-lines should break at a stress equivalent to that produced by about six times the spider's weight.

Because spiders move, jump and fall rapidly, their life is surrounded with various dangers. In such circumstances, maximum efficiency is needed for the mechanical strength of drag-lines. The results described here provide an estimate of this efficiency.

FIG. 2 *Nephila clavata* hanging from a silk drag-line.

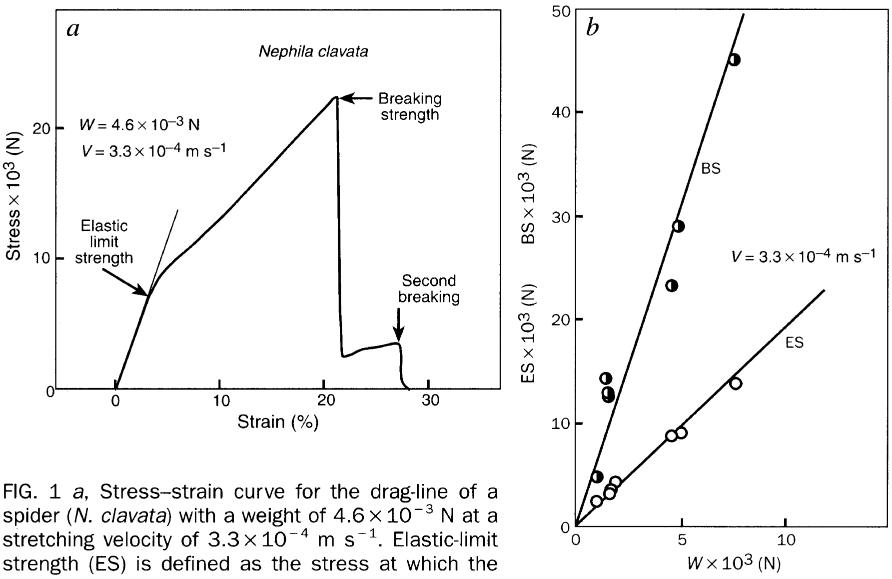

FIG. 1 *a*, Stress–strain curve for the drag-line of a spider (*N. clavata*) with a weight of 4.6×10^{-3} N at a stretching velocity of 3.3×10^{-4} m s^{-1}. Elastic-limit strength (ES) is defined as the stress at which the stress–strain curve alters from linear to nonlinear. Breaking strength (BS) is defined as the stress at the breaking point of drag-lines. *b*, ES and BS for *N. clavata* drag-lines plotted against *W*. Stretching velocity, *V*, is 3.3×10^{-4} m s^{-1}.

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