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On the spider that spits the solution of a nonsmooth oscillator

Spitting spiders (*Scytodes sp.*) are so called because they have the curious habit of ejecting from their fangs a mixture of silk, glue and perhaps venom onto their prey. C. Gilbert and L. S. Rayor have shown that the principal components of the predatory behavior of the spitting spiders usually occurs in the following order: tapping with front legs, spitting a net of glue to pin the prey to the substrate, biting, wrapping and finally feeding.

Fig. 1. *Scytodes thoracica*. Photo credited to Martin Cooper.

The fluid is produced in venom glands and ejected through a very small orifice located at the proximal end of the fang. It is however not yet clear if the spit from these spiders contains some venom or not. The envenomation of prey may indeed occur after its spit-immobilization. The spitting performance parameters of the species *Scytodes thoracica* (Fig. 1) have been measured by R. B. Suter and G. E. Stratton. This spider spits the fluid at a speed as high as 28 m/s (mean ± standard error: 10.32 ± 1.99 m/s), the fang oscillates at a frequency up to 1700 Hz (mean ± standard error: 826.3 ± 102.7 Hz) and the material is deposited during a time less than 35 ms (mean ± standard error: 25.2 ± 1.4 ms). Moreover, the spit is produced as two zigzag patterns, one from each fang (Fig. 2A). The zigzag form of the patterns is a consequence of the spider's fangs' oscillations. More precisely, the lateral excursions of the expectorated silk are caused by the fang's oscillations and those oscillations are spread across the target space by the ventral-to-dorsal motion of the chelicera that bears the fang.

A hydrodynamic forced oscillator model can be used to explain the high frequency of the oscillations because the size of a fang is particularly small for *Scytodes* species. Standard mathematical models can indeed be used to represent the change in angular momentum, the damping force, the tension due to elasticity, the hydrodynamic force arising from the forceful expulsion of fluid and the bookend forces that constrain the fang's motion at the extreme of its excursion. But the zigzag patterns suggest also a discontinuity in the angular speed at each time at which a fang reaches the limits of its feasible motion. Such behavior cannot be obtained from the sinusoidal solution of a smooth oscillator described by a differential equation and must be investigated using mathematical tools from the nonsmooth dynamical theory. Moreover, the nonsmoothness of the dynamics of fang motion has been confirmed by R. B. Suter and G. E.

Stratton by using high-speed video. The fang motion which has been studied in great temporal detail (10 000 frames per second) is not roughly sinusoidal but really nonsmooth. In this paper, we have thus used a nonsmooth oscillator described by a differential inclusion to represent the behavior of the system at the extreme of its excursions.

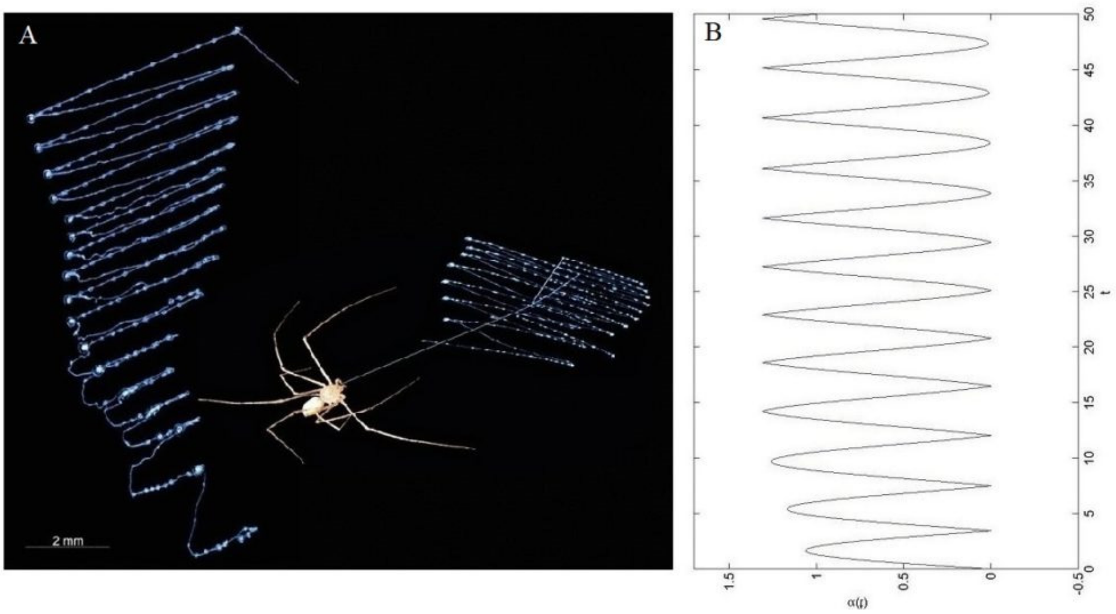

Fig. 2. (A) Zigzag patterns produced by the spit of *Scytodes thoracica*. Source of the photo: R. B. Suter and G. E. Stratton, Spitting performance parameters and their biomechanical implications in the spitting spider, *Scytodes thoracica*, Journal of Insect Science: Vol. 9, Article 62, 1-15, 2009. (B) Zigzag oscillations of a nonsmooth oscillator. The angle of the fang relative to its position at rest is denoted by α.

The resulting biomechanical model treats possible velocity jumps on the same footing as smooth motions. And some numerical simulations show that for certain choices of parameters, the solution of the proposed mathematical model is indeed comparable to the spit of the spider (Fig. 2B).

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