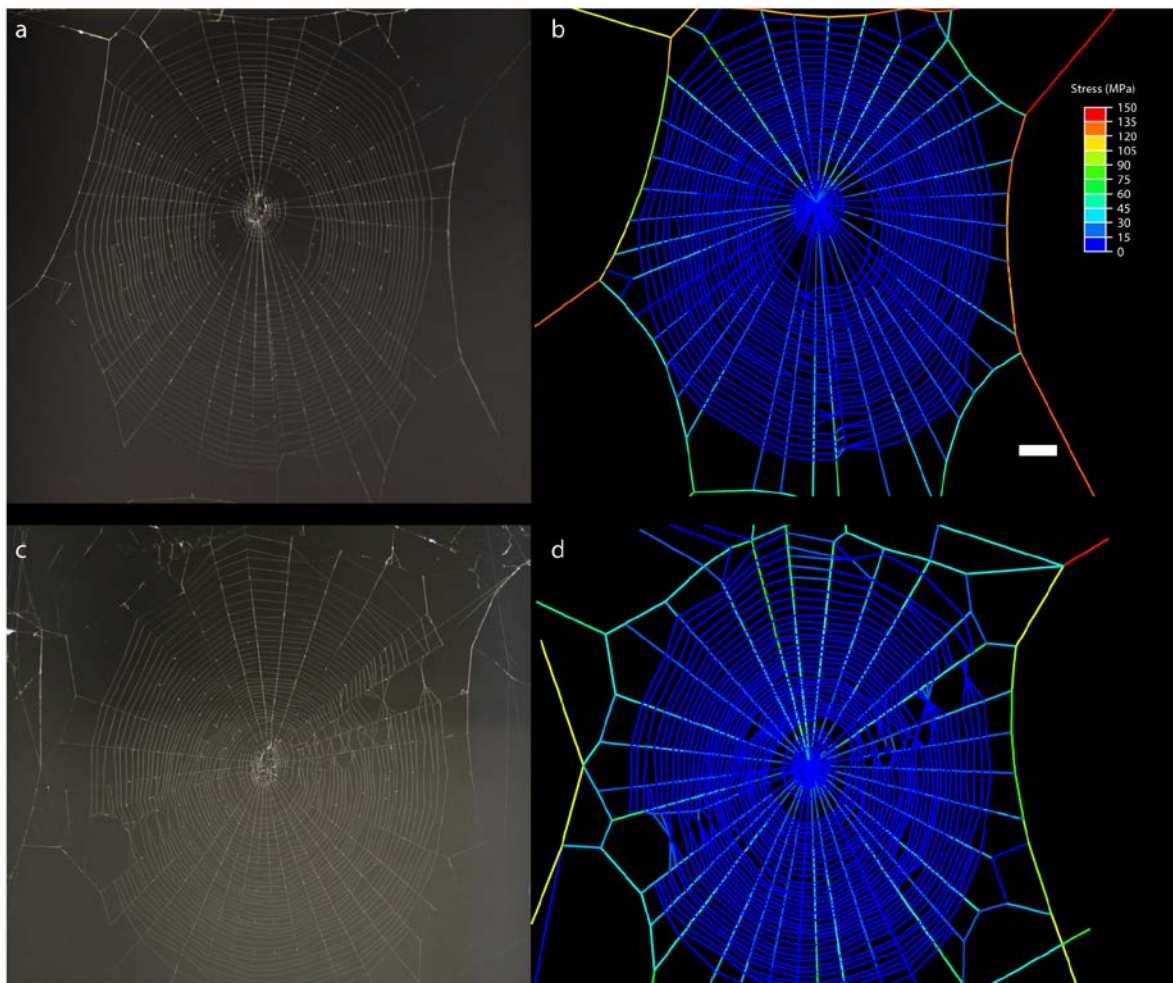
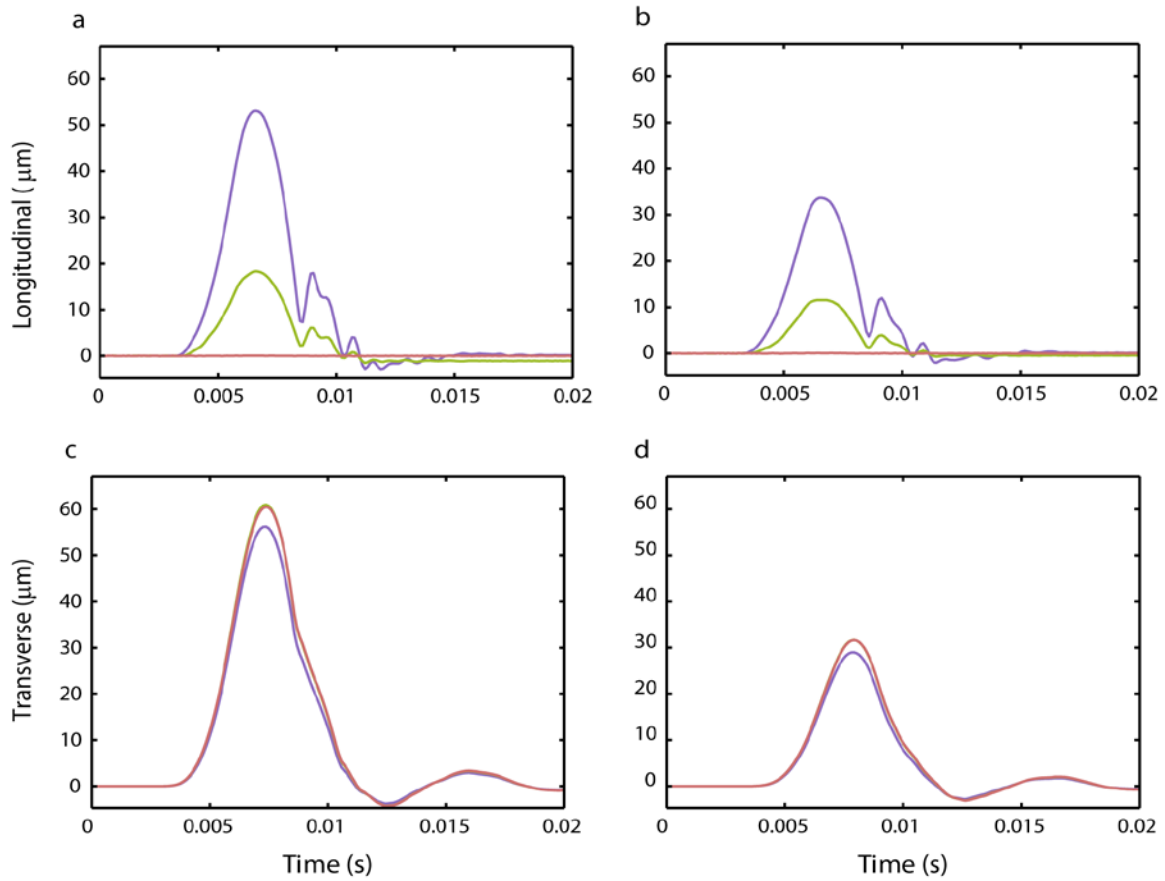


Supplementary Information



Supplementary Figure 1: Modelling of other *Araneus diadematus* webs. a and c) Photographs of the actual webs, b and d) models of the webs, where the colour scale shows pre-stress levels in different parts of the web following equilibrium. a and b) give Web 2, c and d) give Web 3. White bar denotes 20 mm.



Supplementary Figure 2: Effect of input angle on displacement-time profiles for a and b) longitudinal waves and c and d) transverse waves. Red denotes an orthogonal input (90°), green denotes 80° input and blue denotes 60° input. Data are shown 45 mm from source in a and c) and 93 mm from source in b and d). For 80° input, damping for longitudinal waves was -0.82 dB cm^{-1} and damping for transverse waves was -1.17 dB cm^{-1} .

Supplementary Methods:

Spiders were housed in 30x30x5 cm Perspex frames. Every day the spiders that had built a web were given a fly (*Drosophila*) and their web was collapsed for the spider to re-ingest. Spiders were weighed before being released. Webs were photographed with a scale bar and experimental points were mapped onto the digital webs manually.

Connection between the solenoid to the web was controlled using a micromanipulator in three dimensions. The vibrometer (Polytec PSV-400, $50 \text{ mm s}^{-1} \text{ V}^{-1}$) was run in time mode, using no averaging or filters, collecting 2048 samples with a $19.53 \text{ } \mu\text{m}$ resolution (40 ms in total). The vibrometer was triggered with a 1.2 ms pre-trigger time. The PDV-100 vibrometer (Polytec, $500 \text{ mm s}^{-1} \text{ V}^{-1}$) was run in time mode, with no averaging or filters, collecting 2048 samples with a $20.83 \text{ } \mu\text{m}$

resolution (42.67 ms in total), triggered with a 1.28 ms pre-trigger time. The reference start times and maximum displacement amplitudes were averaged across all the data for each web because small deviations in angle or laser position on the solenoid at each position affected the displacement-time profiles.

The two vibrometers were calibrated against each other by comparing velocity-time data for the solenoid input. The time calibration is to allow comparison between the vibrometers only. Both vibrometers were triggered later than the triggering settings (PDV-100 start times were at $2.20 \text{ ms} \pm 0.34$, $N=83$; PSV-400 were at $1.17 \text{ ms} \pm 0.11$, $N=21$). Therefore, all time data for the PSV-400 vibrometer were transformed by adding 1.04 ms onto the time data. The velocity/displacement calibration was authenticated with high-speed camera (Photron UX100 at 10000 fps; thanks for help from Dr Simon Walker) footage of the solenoid which showed that real displacement matched the PSV-400 (a 0.21 mm PSV-400 vibrometer displacement was 0.23 mm displacement with camera), so PSV-100 data were transformed to match by multiplying velocity or displacement data by 0.26.

Experimental velocity-time data were cropped to 22 ms in total length before integration to give displacement-time. The offset was also removed by subtracting the average noise velocity level up to 1.5 ms. Start time was defined for the displacement-time data as five or more points outside boundary (positive or negative) of three standard deviations of the data from 0 to 1.5 ms. Distances were calculated either as the distance between the solenoid and the laser calculated from the web geometry (experimental), or from the input to centre of web, then centre of web to output (for model). Propagation time was calculated for experimental data by subtracting the averaged solenoid start time (with time calibration correction) from the start time, for model data the input start time was subtracted by the model output start time. Transverse wavespeed was then calculated by dividing distance by the propagation time. Speeds were not included in Table 1 if the coefficient of variance was over 150% (eight experimental data samples). Standard deviations of speeds were calculated using the appropriate propagation of errors.

Co-ordinates of local maxima on displacement-time plots were located and compared. Maximum displacement amplitude peaks were filtered as they had to be at least 1 ms apart from each other and over a displacement level of 6 μm . To limit variation, if applicable, peaks were taken from equivalent areas (e.g. 1st/2nd peak or relative to a feature on the graph). Damping was calculated by plotting (Distance[a]-Distance[b]) in cm versus $\log_{10}(\text{Displacement[a]}^2/\text{Displacement[b]}^2)$ in dB and calculating the gradient of the line of best fit. Damping coefficients were not included in Table 1 if displacement of point [a] (closer to the laser) is smaller than point [b] (further from the laser), or if the R^2 value of the line of best fit was under 0.25. Figures were drawn using Adobe Illustrator (CS6) and Matlab software (R2015b).

The finite element models had the same dimensions, number of radii and spiral threads as the original webs. The hub was simplified in order to avoid too small elements that would significantly decrease the stable integration time interval. Truss elements (2 nodes, 1 integration point) reproduced the cable-like behaviour of spider silks. The Young's modulus and range of supercontracted silk moduli were taken from the literature (Supplementary Table 1)¹⁻³. Despite the multiple threads present in a strand of real webs, only one strand was modelled, where the representative cross-sectional area was taken from the literature (Supplementary Table 1).

Supplementary Table 1: Representative diameters and Young's modulus values for the silks threads

Thread	Diameter (μm) ³⁻⁵	Young's modulus native silk (GPa) ¹⁻³	Young's modulus super contracted silk (GPa) ¹
Spiral	2.3	0.06	0.06
Radii	3.5	11	4
Frame, mooring and stiff hub threads	5	11	4

The elastic model meant that no plastic behaviour was modelled and energy dissipation was due to aerodynamic drag only. As discussed in the article, the numerical simulation consisted in two steps. Regarding reaching mechanical equilibrium after imposing an initial pre-tension field, a user element

subroutine was implemented in order to control iteratively the initial pre-tension and reach the desired value of stress on each thread once equilibrium was reached. For the second step, the displacement was applied orthogonally to the web plane. The time-displacement histories due to transverse waves were measured at a control point equivalent to the position selected for the experimental tests.

References

- 1 Liu, Y., Sponner, A., Porter, D. & Vollrath, F. Proline and processing of spider silks. *Biomacromolecules* **9**, 116-121 (2008).
- 2 Gosline, J. M., Guerette, P. A., Ortlepp, C. S. & Savage, K. N. The mechanical design of spider silks: from fibroin sequence to mechanical function. *J. Exp. Biol.* **202**, 3295-3303 (1999).
- 3 Köhler, T. & Vollrath, F. Thread biomechanics in the two orb weaving spiders *Araneus diadematus* (Araneae, Araneidae) and *Uloborus walckenaerius* (Araneae, Uloboridae). *J. Exp. Zool.* **271**, 1-17 (1995).
- 4 Denny, M. The physical properties of spider's silk and their role in design of orb-webs. *J. Exp. Biol.* **65**, 483-506 (1976).
- 5 Wirth, E. & Barth, F. G. Forces in the spider orb web. *J. Comp. Physiol. A* **171**, 359-371 (1992).

Supplementary Movie 1: Transverse wave propagation across a web. Data is shown for Web 1 following input. The video has been slowed down by a factor of 375 (6 second video for 0.016 seconds) with a frame rate of 24 fps. The Z scale (orthogonal to web plane) has been increased by 200 times for clear representation of the relative displacements, but the scale bar gives the real displacements on a colour scale, where the units are in meters.