Measuring the Displacement of A Spider Web Impacted by a Flying Projectile: An Experiment in Biomechanics

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The purpose of this experiment was to measure the displacement of a spider web as a function of time. It has been shown by Lin *et.al.* (Nature 373, 146 (1995)) that a damped sine wave equation with an exponential term well represents the behavior of an orb spider web when impacted by a flying projectile. This study used a different type of web, a three dimensional tangle web to see if the same tendencies were observed. The exponential decay time for the tangle web was measured to be .30±.06 s, while the frequency of vibrations was determined to be 12 Hz. The overall results were somewhat ambiguous, although they do tend to illustrate a general equation of the damped harmonic motion.

INTRODUCTION

Spider webs and spider silk have been an great area of interest for physicists, biologists, and engineers for many years because of the amazingly interesting chemical and physical properties that spiders and their webs possess. Another area of interest for physicist concerns how spider webs are able to dissipate such great amounts of kinetic energy that they encounter when struck by an incoming projectiles, mainly their prey. It has been proved that if a web were built on a human scale, a web resembling a fishing net could capture a passenger plane[2]. Scientists have discovered that webs use their unique geometry to balance stresses and tensions by distributing the forces across their surfaces.

Spiders can build both 2-dimensional orb webs or 3-dimensional tangle webs. A recent area of interest concerning spider webs involves the importance of aerodynamic damping in the dissipation of an insect's kinetic energy upon impact in a web[1]. The stretch and relaxation of threads in a spider web leads to some energy dissipation, but experiments have shown that this form of energy dissipation is too weak to account for all of the energy absorbed by the web, and that only by inclusion of additional aerodynamic damping can the behavior of real webs be reproduced[1].

THEORY

The main theory behind this experiment comes from a study done by Lin, Edmonds, and Vollrath in *Nature*[1]. The main theory behind their experiment pertains to this experiment, while there are also observable differences due to our use another type of web.

Because spider silk is very thin and are impacted by objects with small velocities, inertial forces may be neglected, and viscous forces will dominate[1]. The study by Lin *et.al* showed that the deflection of an intact web as a function of time was well represented by an exponentially damped sine wave of the form

$$D = A\exp(-t/\tau)\sin(2\pi f t) \quad (1)$$

where A is a constant, τ represents the exponential decay time, and the frequency of vibration is indicated by f.

Because this experiment utilizes a tangle web, rather than an orb web, the results that are anticipated are expected to display damped harmonic motion, but the exact equation for the orb web may or may not work for the tangle web

EXPERIMENT

To begin this experiment, a tangle-web spider was obtained and placed in a clear cylindrical plastic container, which was stored upright because spiders instinctively orient their webs toward gravity. After the web had been built, it was also necessary to cut away the part of the container that the web was not attached to in order to get a clear view of the web, unobstructed by any reflection caused by the plastic container. It was important not too cut away too much of the container so that it would retain its rigidity. This was necessary so that threads in the web would not be caused to sag. After this cutting had been completed, a web container stabilizer had to be built from the container itself, two long plastic tubes, a steel rod, and a laboratory jack. The two plastic tubes were taped to the lab jack so that they formed a V-like shape, coming together at one end, and separating at an angle at the other end. The web container was placed so that it was supported by these tubes, and the steel rod was taped across the two tubes, preventing the contained from rolling off the end. After this had been done, it was necessary to complete the entire experimental setup.

A video camera was placed on a tripod, and focused directly onto the exposed spider web. A TV/VCR was connected to the camera because the web was difficult to see with the naked eye. A small table lamp was aimed so that it shined directly onto the web, and a large opaque black cloth was placed in the background of the setup so that the web was more visible.

Next, a 25 mg Styrofoam piece was used as a projectile that would fall on the web, representing an insect flying into the web. A terminal velocity calculation was performed, and the resulting value was found to be $1.24 ms^{-1}$. Then the Styrofoam piece was dropped so that it reached terminal velocity before hitting the web, and the piece was aimed so that it would intersect the middle of the web, and the camera would be able to capture this at a recording rate of 30 frames per second.

ANALYSIS AND INTERPRETATION

After the Styrofoam piece was dropped on he spider web, and this was recorded on video tape, this video tape was then played back into "Avid Video Workshop 3.0." This Macintosh video program was able to make the video into a Quick-Time movie where the user was able to control such things as contrast, brightness, sharpness and the number of colors that needed to be displayed. The purpose of this was to have the video in a format from which data could be taken. After a high quality movie was made, it was saved as a quick time video that could be played in the Macintosh program "2D Video QT," which allows the user to play back the video at a desired rate, and also allows the user to record data points on the video, and save them as a Microsoft Excel file. The following figure represents a frame of the quick-time video from "Avid Video Workshop" program after the Styrofoam piece came into contact with the web.

Fig 1- A frame of video taken after the Styrofoam came into contact with the web.

The "2-D Video QT" program allows the user to set an origin and also to calibrate data. It also allows the user to set a fixed origin on the screen, that may be seen as the user advances the film frame by frame. This option was utilized, and data was taken by setting the origin on a point of a thread of the web prior to the Styrofoam hitting it, and then recording the vertical displacement of this point over the experimental time period. The raw data that was recorded was made into a graph:

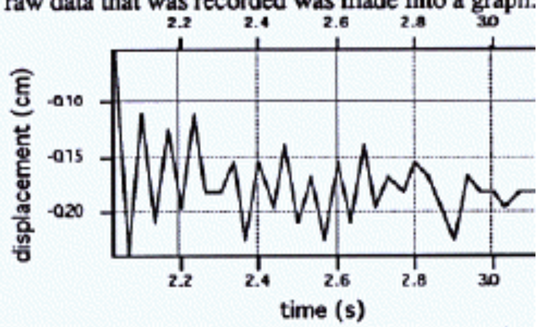

Fig 2- A graph of displacement vs time for the first set of experimental data. This graph represents the vertical displacement of one thread of a tangle spider web after being hit by a 25 mg Styrofoam pellet, traveling at a terminal velocity equal to 1.24m/s.

Next, the peak values for displacement were recorded along with thier corresponding time values. Each one of these peak values was theorized to represent the maximum value in the oscillation of the section of the thread that was observed. In order to deduce the exponential decay time, and calculate what the corresponding "A" constant would be, a graph was made of the peak values vs time. Next, this graph was fit to an exponential curve. The results of this may be seen in Figure 3.

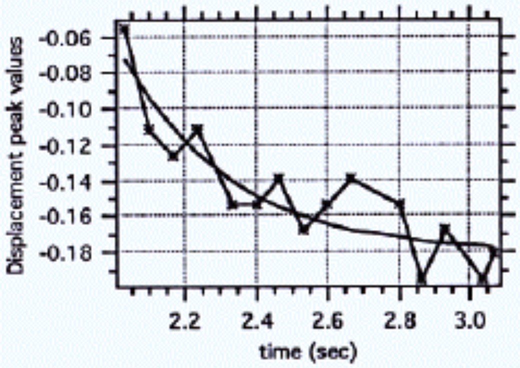

Fig 3- A graph of displacement vs time. Each point on the graph represents the maximum in the oscillation of a point on one thread of the web. The exponential decay time represented here is .30±.06 s.

The exponential decay time was determined to be .296±.06s, and the frequency of vibrations was determined to be 12 Hz. From Figure 1, it was determined that the thread oscillates about -0.18 with an amplitude of 0.11. This was found by using the following equation:

$$A = -0.072 - (-.018) = 0.11 \quad (2)$$

Therefore, these values could be put into the displacement equation (1) to get the following:

$$D = 0.11e^{(-t/.296)}\sin(2\pi * 12 * t) - 0.18 \quad (3)$$

This was done to see if there was any correlation between the equation of displacement for the orb web and the time dependence concerning displacement that was observed in this experiment which used a tangle web. In order to do this, the displacement value which corresponded to time t=0 was examined. This value was determined to be 0.11 cm. Next, this value was substituted into equation (1), and theoretical displacement was calculated over an one second time interval. The theoretical result of this would be that the points corresponding to the observed displacement values would lie on the line of the graph that represented the theoretical displacement values calculated from equation (3). The graph that was produced from this substitution definitely represented damped harmonic motion. In order to determine whether the experimentally observed values for displacement over time corresponded to these values, a plot was made, and may be seen in Fig 4.

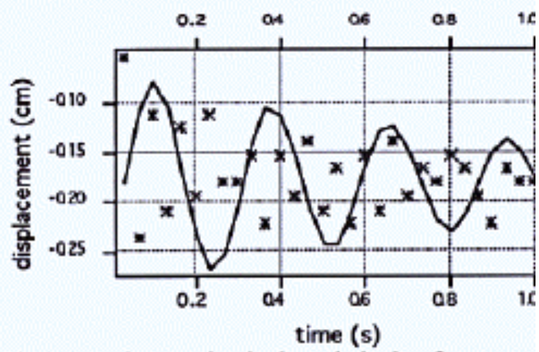

Fig 4- A graph comparing the theoretical values for displacement with the experimentally determined values over a 1 second time interval. The frequencies were each 12 Hz, and the exponential decay time for both plots was .30 seconds. The "A" constant used was 0.11.

The theoretical and experimental values seem to correspond in some manner, as a few of the peak values occurred around the same times, but the exact nature of this relationship was still unclear. From the data that has been analyzed above, it appears that the theory concerning the dependence of time on displacement of an orb spider web is similar to the time dependent behavior that a tangle web encounters when impacted by an incoming projectile. As is evident from Figures 1 and 2, it appears that the displacement equation would follow some type of damped sine law equation including an exponential factor, but the exact nature of this equation was not able to be determined. If this web followed the same laws as the orb spider web, equation (3) would have successfully given accurate values for the constant "A" equal to 0.11. However, as is evident from Figure 4, this was not the case. In the study done by Lin, Edmonds, and Vollrath, it was found that the exponential decay time for an intact orb web was .49 seconds, with a corresponding frequency of 5.41 Hz. The study used a 21 mg Styrofoam bullet whose impact velocity was 1.0 m/s. This experiment found a significantly faster exponential decay time and a much higher frequency, factors which could cause the displacement equation to differ from that of an orb web.

CONCLUSION

The results of this experiment indicated that a tangle spider web and an orb spider web, though structurally very different, both behave in somewhat of the same manner when they encounter a flying projectile. It found that for a tangle-spider web, the exponential decay time was .30 seconds, with a frequency of vibration equal to 12 Hz. For both types of webs, the displacement caused by the impending object showed a time dependent behavior. This behavior appears to indicate an equation for damped harmonic motion, although the exact equation was unable to be determined. The source of the ambiguity of the results has to do mainly with being unable to determine if there is a constant correlation term that could relate the calculated displacement term to the observed displacement term.

REFERENCES

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