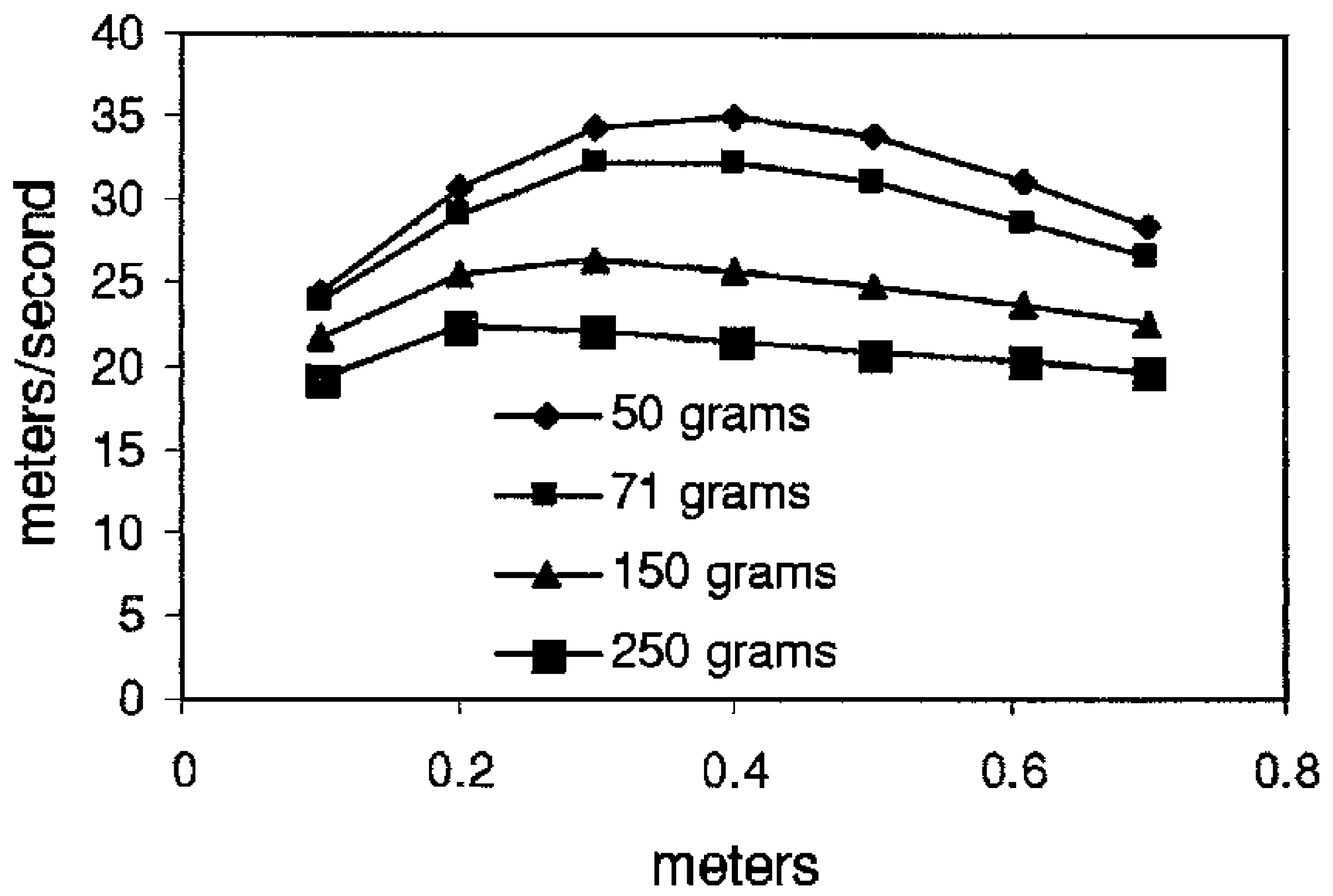

Fig. 7. Velocity versus atlatl length for dart mass equal to 50, 73, 150, and 250 g.

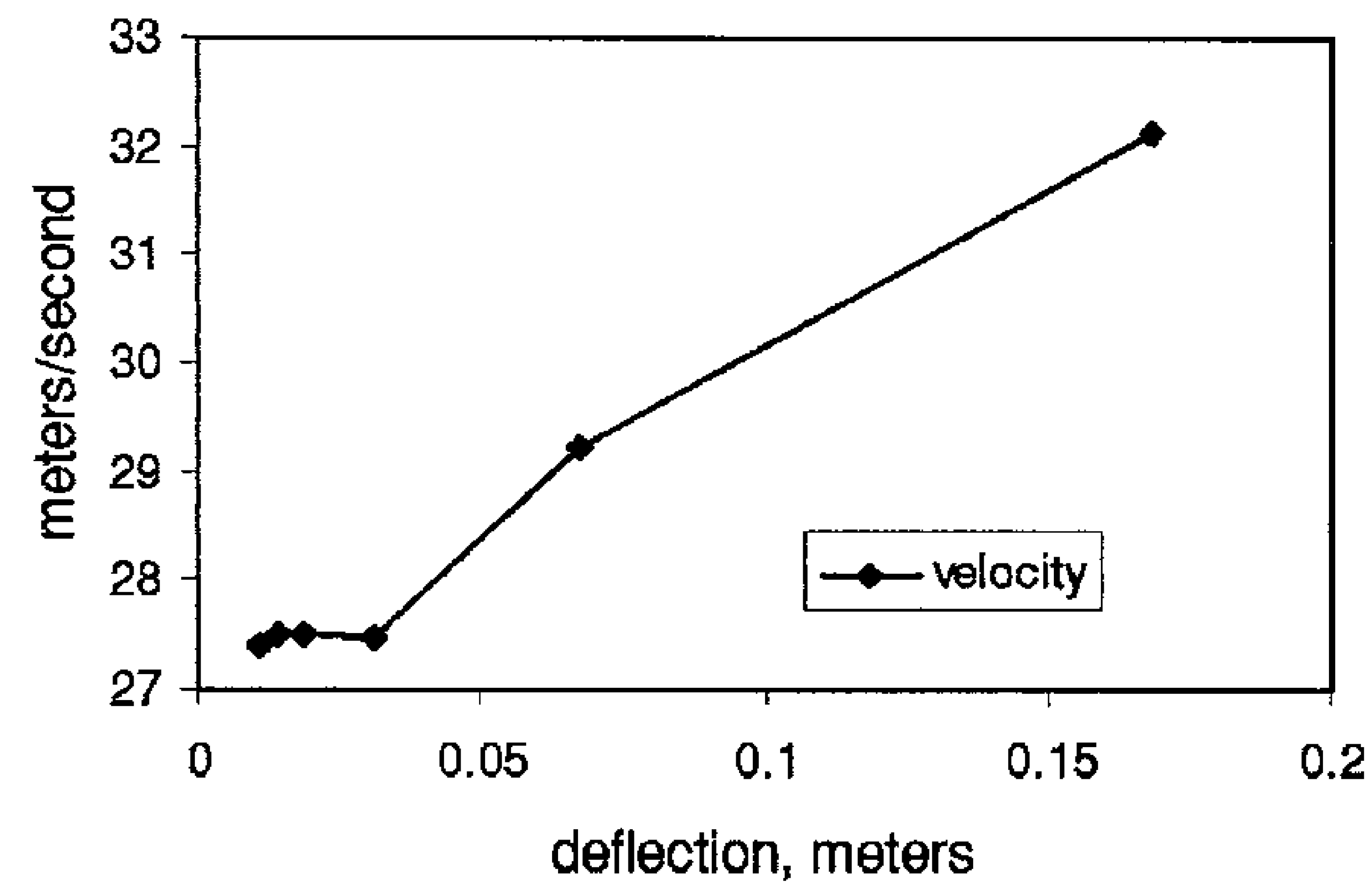

Fig. 9. Dart velocity versus deflection of the spring.

masses involved may not be valid. The force and torque profiles versus hand position may depend on the rate of muscle contraction. It is very difficult to hold a very long dart with a very short atlatl. And the difference in velocity between a long atlatl and a short one may be too small to be perceptible.

VII. ATLATL WEIGHTS

The archaeological record in North America is unusual in that many examples of atlatls have been found with a weight attached near the center. One conjecture is that this weight enabled the hunter to throw with greater velocity. Another hypothesis is that in the final portion of the throw with the throwing hand extended, the hand force strongly negative, and the atlatl nearly vertical, that the negative hand force causes an additional positive torque on the atlatl and increases the terminal velocity of the dart. This hypothetical increase would be more or less negated by reduced horizontal acceleration due to the additional weight. The model is ideally suited to testing this hypothesis. Weights of 50, 78, and 120 g were placed at 0, 0.1, 0.2, 0.3, or 0.4 m from the proximal end of a 0.5 m atlatl and the velocity computed for a 50 g dart. Adding a weight to the atlatl reduced the velocity but not by very much. The results are summarized in Fig. 8.

VIII. ATLATL FLEXIBILITY

Mechanical energy can be stored in the flexing of an elastic structure such as a bow limb, a rubber band, a clock spring, or an atlatl (Fig. 5). There are many examples in nature and in simple machinery where mechanical energy storage is used to increase the efficiency of energy transfer

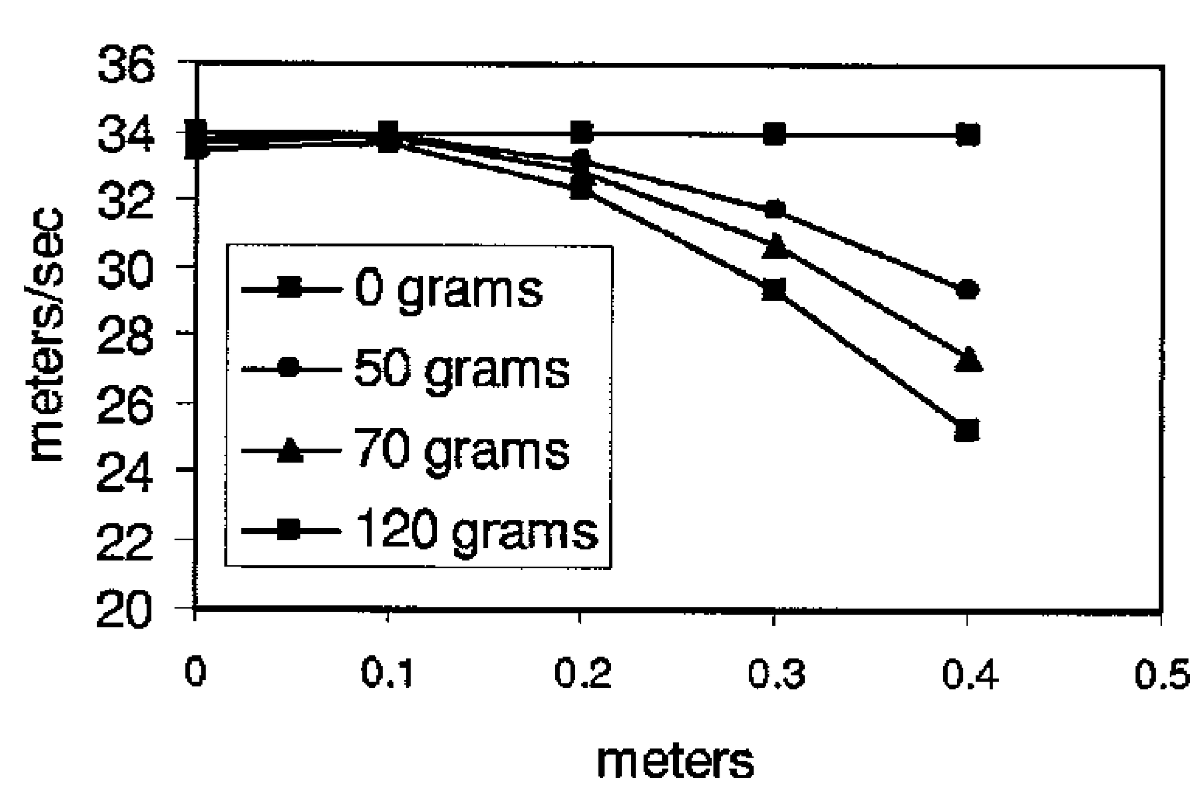

Fig. 8. Velocity versus position of added weight with a 50 g dart and 0.5 m atlatl; the added weight is 0, 50, 78, and 120 g.

from a heavy, slow moving object to a lighter object, a phenomenon called resonant energy transfer. One example is the crack of a whip. The kinetic energy of the heavy whip handle is transferred efficiently along one section of the tapered whip to the next. At the tip the velocity exceeds the speed of sound and we hear a sonic boom. The flexibility of the atlatl has the potential to make a significant increase in the dart velocity because at the instant the dart leaves the spur, there is still some kinetic energy remaining in the atlatl. This possibility was explored by reducing the stiffness of the spring connecting the atlatl spur and the dart. The data for a 71 g dart and atlatl length of 0.61 m are summarized in Fig. 9. The velocity is plotted versus spring deflection distance. The spring deflection is proportional to the force applied to the dart and is inversely proportional to the spring constant. The velocity is plotted for a range of spring deflections that represents actual practice by contemporary users of atlatl. Note that for the range examined the dependence of velocity on spring deflection is a monotonically increasing function with no sharp resonance. The simple model is probably not valid for spring deflections greater than 20% of the atlatl length.

IV. CONCLUSIONS

A high-speed video digitizer was used to capture the coordinates of an atlatl every 0.005 s during a throw. A model of the act of throwing based on this experimental data was then developed. The model was used to predict the behavior of atlatls of arbitrary dimensions used with different projectile masses. The model is sufficiently general that it can also be used for hand thrown spears. A quantitative estimate of the importance of flexibility in the atlatl was presented.

This human/machine system provides an excellent opportunity for additional research. Only one data set was used because there was a 200 mile round trip between my home and the laboratory where the experiment was done. A faster method for gathering velocity versus time data would be very valuable for testing the hypothesis that applied force and torque are independent of the load or velocity. One method would be to attach a low mass sound source to the atlatl spur and use the Doppler shift to measure velocity versus time.[12] Two sound sources with different frequencies could be attached to different places on the atlatl and enable simultaneous measurements of the velocity and angular velocity. The assumption that force and torque depend only on hand position should be verified by throwing with different masses. In practice the force on the dart is collinear with the trajectory only on the average and consequently some rota-