

tional moment is applied to the dart. This moment can be canceled by making the oscillation period of the dart commensurate with the time it takes to throw. Another question that can be investigated is the extent to which small angular variations in throwing effort cause larger changes in the dart trajectory.

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## APPENDIX: THE MOMENT OF INERTIA OF THE HAND PLUS ATLATL

The atlatl used to obtain the experimental data consists of a small diameter rod with constant density per unit length with a weight added near the middle. Its dimensions plus that of the throwing hand are given in Table I. The center of mass is located at a distance

$$C_m = \frac{(0.5L_a M_a + L_w M_w)}{(M_a + M_h + M_w)} \quad (\text{A1})$$

from the proximal end, and the moment of inertia about the center of mass is

$$I_{ha} = \frac{1}{12} M_a L_a^2 + M_a \left( \frac{L_a}{2} - C_m \right)^2 + M_h R_h^2 + M_h C_m^2 + M_w (L_w - C_m)^2. \quad (\text{A2})$$

For atlatls of arbitrary length, the mass is assumed to be proportional to the length.

$$M_a = 0.134L_a \text{ kg/m}. \quad (\text{A3})$$

<sup>1</sup>The World Atlatl Association, (<http://www.worldatlatl.org/>).

<sup>2</sup>A Web site that advertises the Chuckit, a device for throwing tennis balls, is ([http://www.caninehardware.com/products\\_chuckits.html](http://www.caninehardware.com/products_chuckits.html)).

<sup>3</sup>C. Howard, "The Atlatl: Function and performance," *Am. Antiq.* **39**, 102–104 (1974).

<sup>4</sup>M. W. Hill, "The atlatl or throwing stick. A recent study of atlatls in use with darts of various sizes," *Tenn. Archaeol. Soc.* **IV** (4), 37–44 (1948).

<sup>5</sup>Anan Raymond, "Experiments in the function and performance of the weighted atlatl," *World Archaeol.* **18** (2), 153–177 (1986).

<sup>6</sup>P. E. Klopsteg, "Physics of bows and arrows," *Am. J. Phys.* **11**, 175–180 (1943).

<sup>7</sup>Brian Cotterell and Johan Kamminga, *Mechanics of Pre-industrial Technology* (Cambridge U. P., Cambridge, 1992), Chap. 7.

<sup>8</sup>J. L. Palter, "Design and construction of Australian spear thrower projectiles and hand thrown spears," *Archaeol. Phys. Anthropol. Oceania* **12**, 161–172 (1977).

<sup>9</sup>George C. Stone, *A Glossary of the Construction, Decoration and Use of Arms and Armor in all Countries and in all Times* (Jack Brussel, New York, 1934).

<sup>10</sup>T. R. Hester, M. P. Mildner, and L. Spencer, *Great Basin Atlatl Studies* (Ballena, Ramona, CA, 1974), a master's thesis in archaeology on the atlatls and projectiles used in this region.

<sup>11</sup>(<http://www.atlatl.com/>) the Web site for BPS Engineering, the company that made the atlatl and dart used in the experiment.

<sup>12</sup>T. J. Bensusky, "Computer sound card assisted measurements of the acoustic Doppler effect for accelerated and unaccelerated sound sources," *Am. J. Phys.* **69**, 1231–1236 (2001).