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Supporting Online Material for

How Cats Lap: Water Uptake by *Felis catus*

Pedro M. Reis, Sunghwan Jung, Jeffrey M. Aristoff, Roman Stocker*

*To whom correspondence should be addressed. E-mail: romans@mit.edu

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(available at www.sciencemag.org/cgi/content/full/science.1195421/DC1)

Movies S1 to S3

MATERIALS AND METHODS

Force estimate. Viscous and capillary forces are negligible in determining column dynamics, since the Reynolds and Bond numbers are large ($\mathrm{Re} = RU_{\mathrm{MAX}}/\nu > 10^3$; $\mathrm{Bo} = \rho g R^2/\sigma > 1$; with kinematic viscosity ν, water density ρ, surface tension σ, and gravitational acceleration g). Importantly, gravity instead of surface tension is responsible for pinch-off. This is in contrast to recent experiments on the water-exit of cylinders at low Bo (*S1*).

Scaling analysis for the height of the disk at pinch-off, Z_P. We developed a scaling analysis for the pinch-off of the liquid column created by the vertical withdrawal of a disk from a water bath. Consider the horizontal layer of the liquid column located at a distance z beneath the disk, or equivalently, at a height $Z - z$ above the bath, where $Z(t)$ is the disk height at time t (definitions in Fig. 3). The hydrostatic pressure $\rho g(Z - z)$ drives the collapse of that layer, which is balanced by fluid inertia, $\rho(v_R)^2$, providing an estimate for the inward radial speed of the liquid layer, $v_R \sim [g(Z - z)]^{1/2}$. To leading order, the disk speed $U(t)$ can be assumed constant and equal to the maximum speed, U_{MAX}, so that $Z(t) = U_{\mathrm{MAX}} t$. The time of collapse for that layer is thus $R/v_R + z/U_{\mathrm{MAX}}$, where z/U_{MAX} is the time required for its creation. By minimizing the collapse time over all liquid layers [$0 < z < \min(Z, H)$], one finds that pinch-off occurs at the disk at time $t_P \sim \min[(R/U_{\mathrm{MAX}})\,\mathrm{Fr}^{2/3}, H/U_{\mathrm{MAX}}]$ or, equivalently, when the disk reaches the height $Z_P/H \sim \min[(R/H)\,\mathrm{Fr}^{2/3}, 1] = \min[\mathrm{Fr}^*, 1]$, where $\mathrm{Fr}^* = (R/H)\,\mathrm{Fr}^{2/3}$.

Scaling analysis for the column volume, V. When the plate is close to the bath ($Z \ll H$), the liquid column can be considered cylindrical, with height $Z(t)$ and radius R, so that its volume $V(t) = \pi R^2 Z(t)$ increases linearly with the elevation of the disk (Fig. 4B, inset). Gravity alters the radial dynamics of the column (Fig. 3) and slows the volume increase (Fig. 4B, inset). The radius of the column at a fixed vertical distance, $Z - z$, below the disk is reduced (with respect to the initial radius R) by an amount $(2/3)[gU_{\mathrm{MAX}}(t - t_0)^3]^{1/2}$, where $t - t_0 = (Z - z)/U_{\mathrm{MAX}}$ is the time elapsed since the creation of the horizontal liquid layer at height z, which occurred at time $t_0 = z/U_{\mathrm{MAX}}$. This reduction in radius is determined by integrating in time the previous expression for the inward radial speed, $v_R \sim [g(Z - z)]^{1/2} \sim [gU_{\mathrm{MAX}}(t - t_0)]^{1/2}$. The volume of the column is found by integrating the area of each liquid layer over the height of the column,

$$V = \pi \int_0^Z \left[R - \frac{2}{3}\left(\frac{Z - z}{U_{\mathrm{MAX}}}\right)^{3/2} \sqrt{gU_{\mathrm{MAX}}} \right]^2 dz$$

which yields $V/R^3 = \pi Z/R - [8\pi/(15\mathrm{Fr})]\,(Z/R)^{5/2}$ [neglecting $O(1/\mathrm{Fr}^2)$ terms]. The last term is the volume lost due to gravity-driven drainage. Thus, V is maximum ($\mathrm{d}V/\mathrm{d}Z = 0$) when the disk reaches the normalized height $Z_{\mathrm{MaxVol}}/R \approx 0.83\,\mathrm{Fr}^{2/3}$, or $Z_{\mathrm{MaxVol}}/H \approx 0.83\,\mathrm{Fr}^*$. This prediction agrees well with observations (Fig. 4A, open squares).

Filming of cats. Adult cats were filmed during their normal drinking activity. Filming of a personally owned cat (RS) provided the images for Fig. 1 and data for Fig. 2. The liquid used was water, colored with a small amount of yogurt for visual contrast and palatability. Nine more cats were filmed at the Massachusetts Society for the Prevention of Cruelty to Animals (MSPCA) Adoption Center. Cats ranged in age from 1 to 13 years and in weight from 3.6 to 6.7 kg. These cats drank water, occasionally mixed with a minimal amount of tuna water. Lapping frequency f was independent of the liquid used ($f = 3.4 \pm 0.4$ s^{-1} for water and tuna water; $f = 4.0 \pm 0.2$ s^{-1} for water; $f = 3.6 \pm 0.3$ s^{-1} for water and yogurt; $f = 3.5 \pm 0.4$ s^{-1} overall). Videos were collected by waiting until cats drank spontaneously. No cats were forced to drink, deprived of liquids to induce drinking, or otherwise harmed. Filming occurred with a Phantom V5 camera operated at up to 500 frames/s or a Sony HDR-SR5 camera operated at 120 frames/s. In most cases, liquid was contained in a transparent, unobstructed plastic bowl, placed on a digital scale. The video yielded the number of laps, and hence the lapping frequency, while the scale provided the volume per lap.

Image of cat's tongue. At MSPCA, we briefly (<1 minute) photographed a cat's tongue (Fig. 1G), after gently extending it, during a routine intervention on a cat under general anesthesia. No cats were harmed to acquire this image.

Physical model. The physical experiments consisted of lifting a glass disk from the surface of water. The glass disk was initially in contact with the free surface of a water bath and was moved upwards by a motorized linear stage, FiSER (Filament Stretching Rheometer) (*S2*). The distance between the liquid bath (at $Z = 0$) and the bottom surface of the disk, $Z(t)$, was imposed to follow an error-function profile, $Z(t) = \frac{1}{2}H\{1+\mathrm{erf}(U_{\mathrm{MAX}}t\sqrt{\pi}/H)\}$, where H is the final height of the disk, U_{MAX} is the maximum speed attained, and t is the time measured with respect to $Z(t=0) = H/2$, the half-height. This motion profile was chosen because it closely approximates that observed in the vertical motion of the cat's tongue (Fig. 2). As the disk moved upwards, the liquid column was imaged from the side with a high-speed digital camera (Phantom V5) at 1000 frames/s (e.g., Fig. 3; Movies S2 and S3). The shape of the column was then tracked over time using MATLAB's image processing toolbox, beginning with the moment the disk reached the height $Z = 0.03$ cm (this represents the time origin in Fig. 4B). This yielded the time course of the column's volume, assuming axisymmetry. The surface of the borosilicate glass had a static contact angle of 14° with tap water. Experiments were conducted over the following range of parameters: disk radius $R = 2.5, 5, 10, 12.7$ mm; maximum speed $U_{\mathrm{MAX}} = 6$–125 cm s^{-1} and final height $H = 3$ cm. This resulted in the range of aspect ratios $H/R = 2.4$–12.0 and Froude numbers Fr = 0.2–8.0.

Lapping frequency of felines. A collection of recordings performed at the Zoo New England, together with existing YouTube video clips (*S3*), were used to quantify lapping frequency versus body mass. We filmed a lion (*Panthera leo*; 3 events; 55 laps), a tiger (*Panthera tigris*; 2 events; 8 laps), a jaguar (*Panthera onca*; 1 event; 6 laps), and an ocelot (*Leopardus pardalis*; 6 events; 47 laps) during lapping, using the same cameras as above. The lion drank water, while tigers, ocelot and jaguar drank a mixture of water and blood to stimulate drinking. Lapping frequency was obtained from the videos and animal mass from regular weightings by zoo personnel. Analysis of YouTube video clips provided the lapping frequency of cheetah (*Acinonyx jubatus*; 1 video; 67 laps), bobcat (*Lynx rufus*; 1 video; 69 laps), lion (1 video for male, 39 laps; 1 video for female, 24 laps), tiger (1 videos, 11 laps), and leopard (*Panthera pardus*; 1 video, 50 laps). The average weight of these animals was obtained from literature (*S4*).

All research activities with animals complied with and were approved by MIT's Animal Rights Committee.

REFERENCES CITED IN MATERIALS AND METHODS

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S2. G. H. McKinley, T. Sridhar, Filament-stretching rheometry of complex fluids. *Annu. Rev. Fluid Mech*. **34**, 375-415 (2002).

S3. The video clips are posted online at
www.youtube.com/watch?v=Ny6AxgjDp3U (cheetah)
www.youtube.com/watch?v=2-yO0757Awk (bobcat)
www.youtube.com/watch?v=0oTTU49qdVo (lion)
www.youtube.com/watch?v=liziqfmLsJI&NR=1 (lioness)
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www.youtube.com/watch?v=hNpFtE5iUpY (leopard).

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