The Flight of the Seed of *Hura crepitans*

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Ballistic seeds, ones launched explosively, run between about 2 and 4 millimeters in diameter. Most are produced by shrubs or other relatively low vegetation. They usually shoot off at speeds of around 10 meters per second (22 mph, 36 km/hr). The tree *Hura*, by contrast, launches 16 millimeter seeds at 70 meters per second (150 mph, 250 km/hr)—giving each seed roughly 100 times as much initial momentum. Launch is a dramatic event; if indoors, it produces quite a startling level of sound.

The physical performance of this champion among ballistic seed-launching plants deserves a bit of attention. For that matter, our ordinary notions of projectile motion, products of our elementary physics courses, prove quite inadequate to describe what it does and what adaptive advantage might have pushed it to such extreme performance.

One can easily calculate that a projectile with an initial speed of 70 meters per second, shot off at an optimal launch angle (from horizontal) of 45º, should go nearly 500 meters. And that assumes ground level launch and landing—if launched from 20 meters up, as *Hura* might, it will go considerably farther. But the usual calculation ignores air resistance, drag, which although (marginally) acceptable for cannon balls, turns out to be hopelessly unrealistic for small, less dense objects. An iterative computation that makes reasonable approximations of drag tells us that a seed of *Hura* loses no less than 94% of its theoretical range—assuming ground-level launch and landing. The figure below puts that in a general bioballistic context.

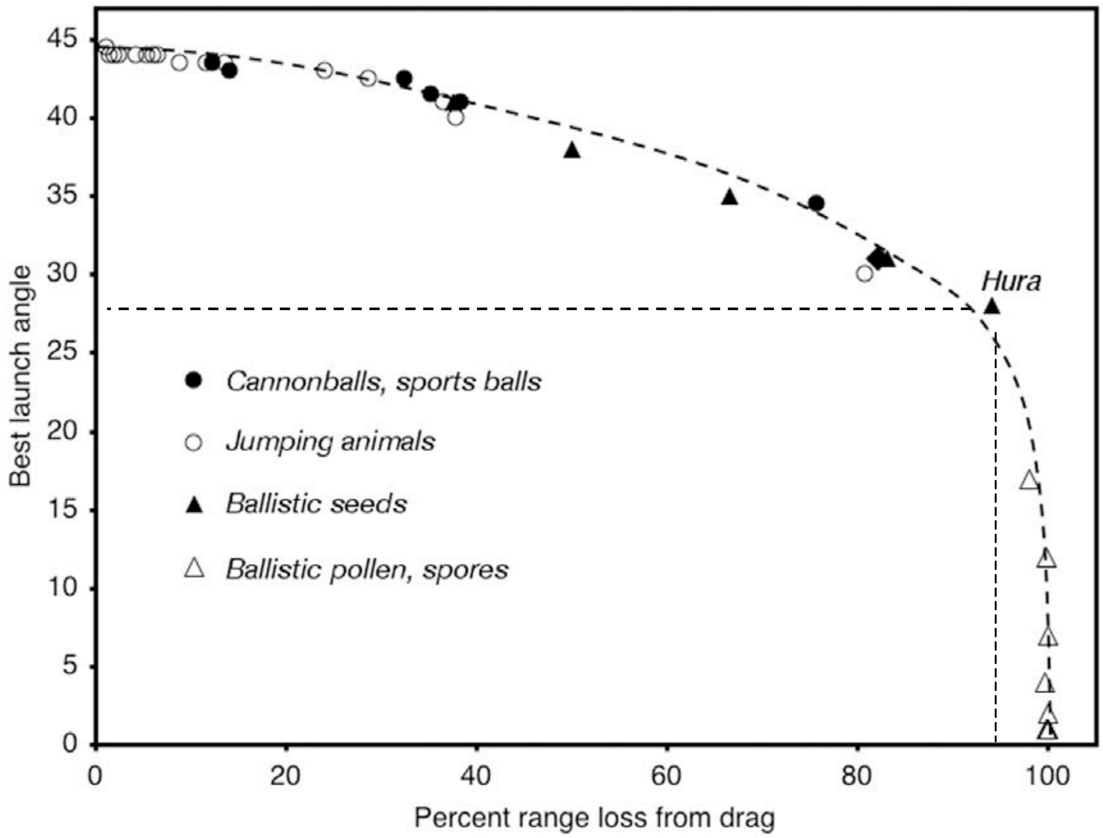

Fig 1. The relationship between the launch angle that carries a projectile farthest and the loss of the ideal (in vacuo) range to drag. *Hura* does best at 28º and loses 94%. The other projectiles are identified (lumped, really) by the different symbols.

Its draggy path would thus carry it only 30 meters from launch back to launch height. And with high drag trajectories, the optimal launch angle drops well below the 45º of the basic physics textbooks. What happens is that drag makes speed a precious resource, and the projectile goes farthest if it uses that more of that high initial speed to get some distance outward and less to get altitude.

Furthermore, these high drag trajectories deviate considerably from the parabolic ideal, something that will be important shortly. The figure below gives the computed trajectory of a *Hura*-like projectile from launch back to the same height when shot at that 28º angle that gives greatest horizontal range—assuming launch and landing are at the same height. (For spores, spore clusters, and pollen grains, trajectories are even less parabolic, descents even closer to vertical, and best angles even lower—down to 1º for a 10-micrometer *Gibberella* pollen grain.)

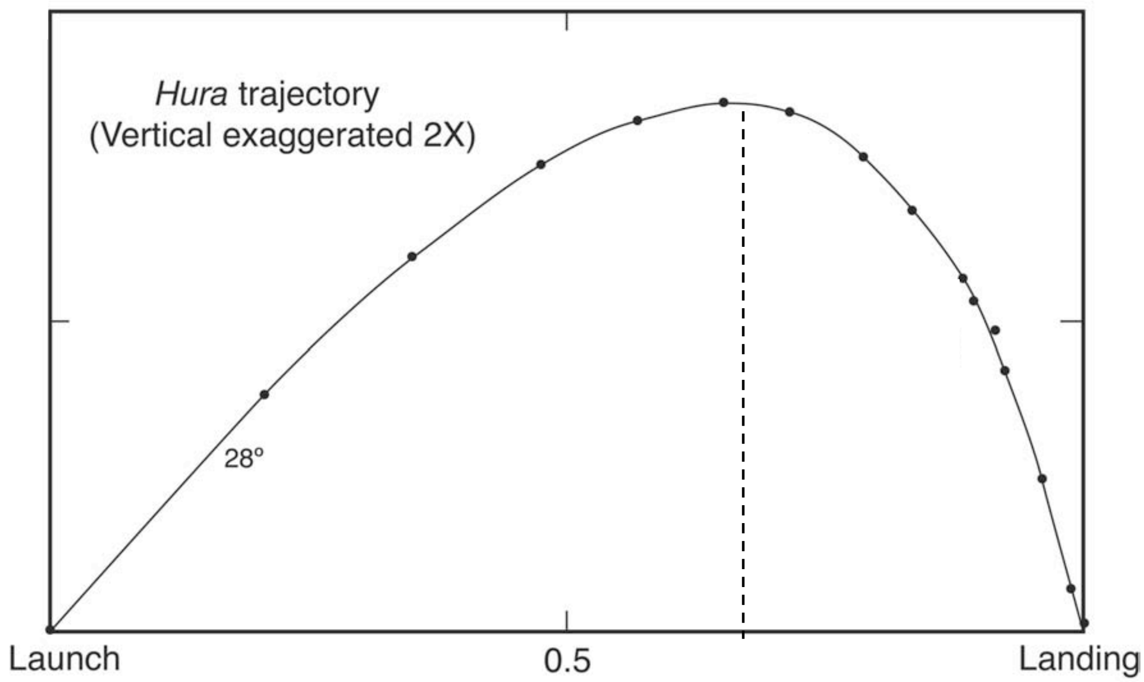

Fig. 2. The computed trajectory of a seed of Hura when launched at a 28º elevation. Notice that the curve isn't a tidy, symmetrical parabola—it peaks well beyond the half-way mark.

Getting up to a high speed in a very short distance demands a prodigious acceleration. *Hura* needs an average acceleration of 41,000 meters per second squared, about 4000 times the acceleration of gravity. No other biological object of comparable size comes anywhere close to such a value—only tiny spores, spore clusters, and pollen grains do better. That, though, brings us to the curious way in which acceleration varies with size. Very simply, Newton's second law, the assertion that force equals mass times acceleration, defines the game. For the output of most motors or the strength of materials, force varies with length squared (essentially cross section). Mass varies with length cubed (assuming constant density). Therefore acceleration should vary inversely with length—we expect small projectiles to achieve high values of acceleration just as a matter of scaling. *Hura* seeds, for their size, are indeed exceptional accelerators.

The figure that follows plots acceleration against size for a large and diverse assortment of biological projectiles. One does find approximately an inverse-length scaling rule—a limit line with a slope of –1 (on a log-log plot) fits reasonably well to data for this diversity of bioballistic items that encompasses a five-order-of-magnitude size range. No special strengths need to be assumed for tiny projectiles or guns despite accelerations that can approach a million times that of the earth's gravity. (The regression line is similar, but it should be distrusted inasmuch as data for bioballistically mediocre performers have been arbitrarily excluded.)

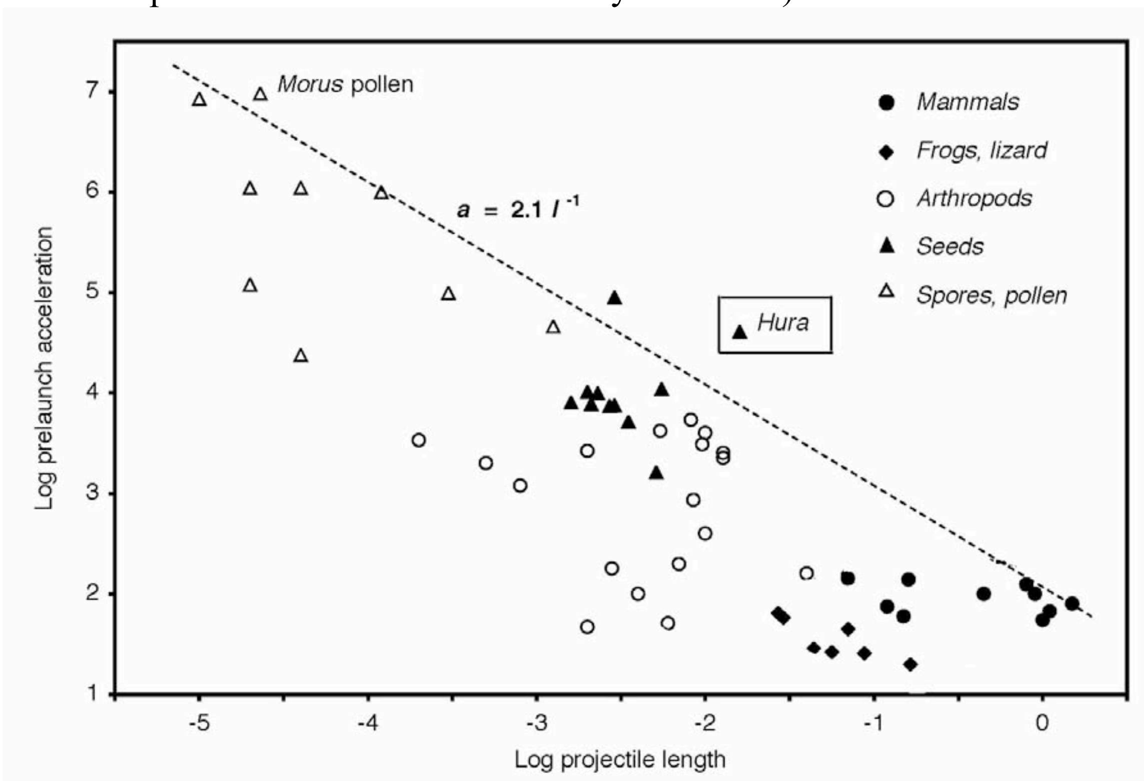

Fig. 3. Acceleration (meters per second squared) versus projectile size (average length or diameter, in meters, not volume)—from a 10-micrometer spore on the left to a 2-meter jumping cougar on the right.

But *Hura* is exceptional, well above and to the right of the line. (Remember that this is a highly expanded log-log plot.) For its size, it has an exceptionally great prelaunch acceleration, as mentioned earlier. Nothing, of course, precludes exceptional performance. What it takes is a greater-than-ordinary investment in projection gear—a whopping great gun. And it implies a whopping problem with gun recoil. After all, momentum has to be conserved. If you throw something forward, you have to brace yourself against being pushed back. Recoil, of course, amounts to a tax on acceleration just as drag is a tax on speed. So it's not just something that the system must be strong enough to withstand.

What's the advantage of such a high speed, with the concomitant investment in the explosive equipment? *Hura*, unusually, (as noted) is a tree, not a shrub, and, at maturity, a fairly tall one with a large crown. If the name of the game (adaptationally speaking) consists of getting out from under the maternal tree, then it has to go farther than some seed produced by a small shrub. One might expect that the greater launch height would take care of the problem. In this world of high drag projectiles, though, that much more vertical descent—look back at Fig 2—limits the benefit of launch height. Thus a *Hura* seed launched at 28º has gone 30 meters horizontally when it gets back to the height from which it was launched. Descending, say, an additional 20 meters (not on the graph) to the ground yields only an additional 3.5 meters horizontally—its downward course has an 80º average angle. So escaping the maternal or step-maternal apron-strings must rely mainly on either larger size (lower drag relative to weight) or higher launch speed or both.

And it has a way to deal with recoil. It shoots seeds out in all (at least in two dimensions) directions at once. Thus the recoil of one seed is invested in accelerating others rather than in a fruitless (sorry) attempt to change the rotation of the earth—as one can see from the picture of the fruit in the La Selva Digital Flora.

Sources…

The basic experimental data comes from…

Swaine M D and Beer T 1977 Explosive seed dispersal in *Hura crepitans* L. (Euphorbiaceae); *New Phytol.* **78** 695-708

I've described the situation in a pair of essays (rewritten and expanded in a book that's now in press…

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A demonstration version of the computer program for draggy trajectories, by Tiffany Chen, can be found at…

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