OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

Nature's Engineers: Learning from the Insect World

Eric Sim
hsim@taftschool.org

ABSTRACT

Biomimicry is one of humanity's greatest tools. Nature is one of, if not the greatest, source of knowledge and innovation. The field of entomology (the study of insects) has yielded many inventions and enhancements used in our everyday lives without our notice. Many studies have drawn useful information from the world of insects, but the public is often unaware that the very creatures they call pests are quietly improving how they live. People may know a few instances; they rarely grasp the sheer amount of inspiration we take from entomology. To address this gap, this review examines several innovations, some already in use and some still emerging, in detail, and weighs how far each has actually traveled from the insect to the laboratory to the world. It sets out the search behind that selection, and gathers the examples into a summary table that gives the mechanism, the application, and the stage each one has reached. The aim is to introduce the reader to the small superheroes in their lives, and to be honest about which of their powers we have truly learned to copy.

INTRODUCTION

Technology is undergoing a massive leap in advancement as it draws function and purpose from natural sources. Humans are not the only inventors in the history of technological progress; hundreds of orders of organisms have shaped it, and continue to. One of the largest contributors in this pool of non-human inventors is the order Coleoptera, the beetles, whose influence on human engineering is too large to ignore. The elytra of beetles have helped engineers design more efficient airfoils for aircraft and wind turbines. Their exoskeletons have informed 3D printing and the search for materials that are light and durable at once. The technology behind frost-free surfaces traces back to the bumps on a beetle's shell. Agility in many robots is programmed to mimic the movements of certain beetles.

After several weeks of reading, I have compiled a series of innovative technologies that have drawn inspiration from the world of beetles, and the section below sets out how that reading was done. There is a substantial body of engineering that has grown out of entomology, and a good place to begin is the influence of beetle elytra on the wings of unmanned aerial vehicles (UAVs) and micro air vehicles (MAVs).

Sep 2026
Vol 11. No 1.

METHODOLOGY

This is a narrative review, not a systematic one, and the search behind it was straightforward. Over roughly six weeks in the spring of 2026 I searched Google Scholar, ScienceDirect, and SpringerLink for peer-reviewed work, and used Nature Portfolio, Advanced Science News, and TechXplore to catch newer projects that had not yet reached a journal. The search terms were pairs of an insect word and an engineering word: beetle elytra and airfoil, exoskeleton and composite, hydrophobic and Namib, insect and jumping robot, dung beetle and optimization algorithm. Where a news article looked promising I followed it back to the paper it was reporting on and read that instead.

A source had to do three things to make the cut. It had to name the insect and the mechanism rather than gesture at nature in general. It had to report something measured, whether in a wind tunnel, under a microscope, or in a simulation. And it had to connect to an engineering use, either one already built or one clearly proposed by the authors. I kept to sources in English, relied on the primary paper wherever one existed, and used news coverage only to find that paper or to describe work too recent to have one. Popular articles that made a claim with no study behind them were left out, and so were sources that turned out to be repeating a single original finding rather than adding to it. The examples that follow are not every insect-inspired technology that exists; they are the ones where the biology has been measured and the engineering has been attempted.

AIRFOILS DERIVED FROM ELYTRA

Flight is one of the most important facets of engineering. Whole industries depend on it, and so do the world's militaries, for travel and reconnaissance alike. Reconnaissance drones such as UAVs are constantly being pushed further, and one advantage engineers want for them is multi-locomotion: the ability to fly and also cross terrain on the ground. That ambition raises a problem. How do you protect the wings during travel on the ground without weighing down the flight? Heavier, more durable wings are not an option, because the added mass ruins the flying. To get around it, engineers turned to biomimicry.

They studied the elytra of beetles. Elytra are the hardened forewings that fold back over a beetle's membranous flight wings, shielding them when the insect is grounded and swinging clear when it takes off. They guard the delicate wings while staying light enough not to drag the beetle down. A research group at Konkuk University in South Korea, including Hoon Cheol Park and Doyoung Byun, studied this arrangement in the Japanese rhinoceros beetle, *Allomyrina dichotoma*, and built small flapping-wing aircraft modeled on it (Sitorus et al., 2010). It is the same solution the drone problem was asking for: a cover that protects the wings on the ground without grounding the flyer.

The added weight of a wing cover should hurt flight, yet the elytron earns some of that weight back. Its cambered shape, a streamlined curve more accentuated on top than underneath, produces positive lift even when it is held flat to the oncoming air. Wind tunnel tests and three-dimensional simulations in ANSYS-CFX software showed something more useful still: the elytron keeps generating lift at steep angles of attack, past the point where an ordinary airfoil would stall (Sitorus et al., 2010). On its own the force is small. A single elytron produces vertical force equal to only about two percent of the beetle's body weight, not enough to carry even itself. What changes the picture is interaction. Airflow shed by the beating hind wing raises the force on the elytron by roughly eighty percent, and together the two surfaces lift the whole insect. For engineers the appeal is that one surface does two jobs at once: armor that also resists stall.

This marriage of protection and flight shows up most in unmanned aerial vehicles and micro air vehicles, the small reconnaissance drones that raised the problem in the first place (AerialCore, n.d.). The same behavior, a cambered surface that keeps its lift at high angles, informs helicopter blades, aircraft wings, and turbine blades. Anything built to hold itself in moving air has something to learn from the elytron.

Flight will keep drawing on this one insect solution. It may be an early step toward morphing wings, wings that change shape in mid-flight to suit the moment. And the elytron is only the visible edge of a larger structure. It is one hardened plate of the exoskeleton, and the exoskeleton holds far more than armor.

BIOMIMICRY MATERIALS FROM INSECT EXOSKELETONS

As structures grow more ambitious, the materials that build them have to keep up, and material designs have to come from somewhere. Increasingly, engineers are taking them from insect exoskeletons, which balance sturdiness, flexibility, and lightness better than most things humans make.

Most exoskeletons are built from chitin, a naturally occurring polysaccharide: a long-chain polymer of linked N-acetylglucosamine units (ScienceDirect, n.d.). It is tough, light, and biodegradable, and its derivative chitosan carries antibacterial and wound-healing properties that medicine already puts to use (Frontiers, 2025). Because it breaks down cleanly and sits safely against living tissue, chitin draws interest wherever sustainability and biocompatibility have to hold at the same time, from surgical materials to, potentially, a cheaper stand-in for the carbon fiber used in cars (Stuttgart University, n.d.).

Some of our most advanced materials already exist in miniature on an insect. A weevil's snout has the layered look of fiberglass or carbon fiber. Work by Nikhilesh Chawla and Michael Jansen in Nico Franz's lab at Arizona State University found that the snout is built from alternating soft and hard layers stacked in a helix, an arrangement that leaves it flexible enough to twist yet hard enough to bore into a nut (Arizona State University, n.d.). Under a microscope the layers sit at set angles to one another, each turn adding to the whole.

Robotic joints have borrowed from the limbs of mantises, whose folding forelegs sweep through a wide arc without giving up strength.

The exoskeleton hides structural tricks too. A team at Monash University led by Wenhui Duan looked at the segmented armor shared by fleas, scorpions, and centipedes, more than eighty percent of known animal species, and found a load-bearing pattern that had gone unnamed among the eight design motifs engineers already draw from nature (Wang et al., 2022). Instead of meeting a crushing force head-on, the segments rotate against one another, dissipating energy and failing one piece at a time rather than all at once. The researchers 3D-printed the pattern into a lightweight cement composite. It held together through slow, contained failure and showed around two hundred percent higher strength than the equivalent cellular structure, while using less material. Stronger, lighter, and less to mine and burn.

The toughest of them all is the diabolical ironclad beetle, *Phloeodes diabolicus*. It cannot fly, so it survives by refusing to be crushed. It can take a load of about thirty-nine thousand times its body weight, roughly fifteen kilograms of force pressing on a two-centimeter insect, enough to walk away from a car tire (Rivera et al., 2020). The secret is in the seams. Where the two halves of its wing cases meet, the joints interlock like the teeth of a jigsaw puzzle, and under pressure those interlocked blades peel apart layer by layer instead of snapping clean, bending a hard blow into small, survivable damage. The design points toward joining stiff, brittle materials without the welded or bolted weak point where things usually fail.

Learning to build materials that carry the advantages of an exoskeleton would be a real step forward, and the payoff reaches past strength into medicine, sustainability, and safer construction. The exoskeleton is not only armor, either. Some insects use it to camouflage or to find mates, and one desert genus uses it to drink.

FROST-FREE AND HYDROPHOBIC SURFACES

A problem engineers have fought for a long time is frost. It forms when water vapor condenses onto a surface and freezes, and it needs almost nothing to start: one droplet freezes, throws an ice bridge to the droplet beside it, and freezes that one too, and the sheet spreads. Removing it is slow and expensive, and heavy with chemicals. Frost on wings is a common reason winter flights sit on the ground.

So engineers turned to hydrophobic surfaces. A droplet lands, but instead of wetting the surface it beads: the edge of the droplet meets the surface at more than ninety degrees, the surface tension holds, and the bead rolls off. Push further and you get superhydrophobic surfaces, where the contact angle passes a hundred and fifty degrees and the droplet can barely sit still long enough to freeze. Both are being tuned continuously, balancing how well they shed water against what they cost to make.

To push past even those, engineers went to the desert. On the dunes of the Namib lives a beetle, long identified as the genus *Stenocara*, that drinks fog. Andrew Parker and Chris Lawrence described the mechanism in 2001: the beetle's back is studded with smooth bumps about a millimeter apart, the bumps water-attracting and the waxy troughs between them water-repelling (Parker & Lawrence, 2001). In the early fog the beetle tilts into the wind, droplets gather on the hydrophilic peaks, grow until they are heavy enough to tear free, and roll down the hydrophobic channels into its mouth. The alternation is the whole trick, wettable islands to catch the water and slick valleys to move it.

The story is not fully settled, which is part of what makes it worth studying. Later work questioned whether this beetle really fog-basks in the wild, and even re-identified the specimen in the original study as a different genus, *Physasterna* (Nørgaard & Dacke, 2010). What survives the argument is the surface principle itself. A patterned array of water-attracting and water-repelling regions, once engineers reproduce it, slows and sometimes halts frost: space the wettable spots far enough apart and a condensing droplet cannot bridge to its neighbor and grow into a sheet of ice.

From there the uses branch out. The same kind of surface can pull drinking water straight from humid air, cheaply and without power (ScienceDirect, 2024). Droplets rolling off carry dust and grime with them, which makes for self-cleaning coatings on the things frost and dirt punish most, aircraft skins and power lines (TechXplore, 2024). Fewer outages, fewer de-icing crews, fewer delayed flights. A related version of the surface separates oil from water by their different affinities, turning a fog-drinking beetle into a tool for cleaning contaminated water (ScienceDirect, 2024). What began as one beetle's way of surviving a dry morning opens onto water supply, infrastructure, and cleanup, and engineers are nowhere near the limits of it.

INSECT-DERIVED BIONIC JUMPING

Robotics is a fast-growing field, metal and machines built to copy the living. Recent robots have mimicked dogs, hamsters, even humans, and they have looked to insects too. Of all the things a robot might borrow, the mechanics of jumping have drawn special attention, and insects such as fleas and locusts have shaped how a robot leaves the ground.

Fleas are pests, and fleas are extraordinary. A flea launches itself many times its own body length in a single jump, reaching take-off speed in about a millisecond (Sutton & Burrows, 2011). It does not do this with muscle alone, which is far too slow. It stores the energy first, compressing a pad of resilin, a rubber-like protein, in its thorax, then releases it all at once through the leg segments, which act as levers driving the foot against the ground. Muscle winds the spring slowly; the spring fires it fast. That is a catapult.

Flea beetles run the same play with a latch. Their enlarged hind legs bend and load elastic energy into the joint, held in place until a catch lets go and the stored energy leaves in an instant (Nadein & Betz, 2016). The sudden, total release is what buys the distance. Winding up and releasing slowly would get the beetle nowhere.

Locusts store their energy in a different place, the femur itself. Paired semi-lunar processes in each hind leg, composites of hard cuticle and resilin, bend under a slow muscle pull and snap back on release (Burrows & Sutton, 2012). Locusts are studied not only for how far they jump but for how they hold their orientation in the air and land upright, managed through a mix of controlled body rotation and timing.

Engineers have poured these mechanisms into robots. Elastic materials, epoxy resin or carbon fiber, sit in a robot's limbs to gather and store energy the way cuticle and resilin do (MDPI, 2023). A latch or trigger matters as much as the spring, because releasing the stored energy in a shorter burst raises the push-off force.

Jump height can even be tuned with electrostatic adhesion (Wiley, n.d.). Charged pads hold the robot to the ground with an electrostatic force set by the applied voltage; the stronger the grip before release, the lower and more controlled the hop. Let go early and it jumps high, hold longer and it jumps low.

One robot, TumRo, carries two ways of moving in a single body (Advanced Science News, n.d.). It is a spool about 320 millimeters long with a wheel at each end and a cage of flexible metal ribs between them, so it can roll across ground on its wheels. To jump, it compresses until its own weight tips it onto its side, the spool folding inward like a collapsing lantern. Then it trips a latch, the stored energy snaps it straight, and it launches off the ground.

Movement of every kind, in robotics and in engineering at large, can draw on entomology. Jumping is only the start, and researchers have not found half of what is there. Running on water or crossing broken ground may be next. Proportionally, insects are the best jumpers on Earth, and there is a great deal still to learn from them.

DUNG BEETLE OPTIMIZATION (DBO)

Not every lesson from an insect is physical. Some are behavioral, and one has become a tool in code. In 2023, Jiankai Xue and Bo Shen introduced the Dung Beetle Optimizer, an algorithm that borrows the habits of dung beetles to solve hard optimization problems (Xue & Shen, 2023). Real dung beetles, members of the scarab family, collect the droppings of large grazers, roll them into balls, and haul them off to bury and feed on. Xue and Shen mapped each stage of that life onto a step in a search.

The algorithm begins by scattering a population of virtual beetles across the space of possible answers, each one a trial solution, many at once so that good answers surface faster. Then it moves through the beetle's behaviors in turn (Xue & Shen, 2023). Think of each simulated beetle as one attempt among many to find the best answer.

In the rolling phase, a beetle pushes its ball toward better ground, which stands in for searching outward from the best answers found so far. When it meets an obstacle it performs a "dance," reorienting to strike off in a new direction, so the search is never walled into one patch. Foraging models a closer, finer sweep of promising nearby ground. Stealing lets beetles take from one another's finds, exploiting the best solutions the group has already located. And reproduction spins new candidate solutions off the best-performing ones, the way the beetle breeds to carry the line forward. Weak answers fall away; strong ones parent the next round.

The Dung Beetle Optimizer is a process of elimination in beetle costume, and it has spread quickly into problems from engineering design to drone path planning, valued for converging fast without throwing away good answers on the way. Understanding how an insect behaves, it turns out, can be as useful as understanding how it is built.

UTILITY MATERIALS BASED ON THE GOLDEN TORTOISE BEETLE

The golden tortoise beetle earns attention at both ends of its life. Its larva builds a shield on its back out of shed skin and its own droppings, a defense it can top up from waste it already makes, in effect a self-renewing armor (Missouri Department of Conservation, n.d.; Roundglass Sustain, n.d.). Engineers read that as a hint: a protective material that repairs itself from cheap, discarded input, reused rather than thrown away. If waste could be turned back into usable material this way, the environmental math would shift.

The adult carries a different marvel, a shell that changes color. In the closely related Panamanian tortoise beetle *Charidotella egregia*, the cuticle is a stack of thin layers whose spacing decides which wavelengths of light bounce back; when the beetle is disturbed, it moves fluid into and out of the gaps between those layers, and the mirror-bright gold shifts to dull red (Vigneron et al., 2007). No pigment switches on. Only the geometry of the layers changes. Engineers want exactly that: a surface that tunes its own color or brightness by moving fluid through it, no LEDs and no power-hungry display.

Most material work chases strength or flexibility. This beetle points somewhere else, toward materials that are visual and responsive, that signal and adapt. As displays, sensors, and smart surfaces spread, that kind of tunability is worth as much as toughness. As a source of inspiration for the visual side of materials, the golden tortoise beetle is hard to beat.

HOW FAR EACH HAS TRAVELED

The examples above are not equal, and putting them under one heading hides that. Some rest on decades of measurement and a product a person can already buy. Others rest on one paper and one prototype sitting on a bench. Table 1 sets them side by side, with the insect, the mechanism, the use engineers have made of it, and the stage that use has actually reached.

Table 1. Insect-inspired technologies covered in this review, with the stage each has reached.

Insect	Mechanism mimicked	Engineering application	Stage reached	Reference
Japanese rhinoceros beetle (*Allomyrina dichotoma*)	Cambered elytron that shields the folded flight wings and keeps generating lift past the stall angle	Protective wing covers and airfoils for UAVs and MAVs; blade design	Laboratory prototype	Sitorus et al., 2010; AerialCore, n.d.
Insects generally (chitin)	Tough, light, biodegradable polysaccharide; chitosan is antibacterial	Surgical and wound-care materials; proposed low-cost substitute for carbon fiber	Commercial in medicine; concept as a structural material	ScienceDirect, n.d.; Frontiers, 2025
Weevil (snout)	Alternating soft and hard layers stacked in a helix	Layered composites that are flexible and hard at once	Concept	Arizona State University, n.d.
Fleas, scorpions, centipedes (segmented armor)	Segments rotate against one another and fail one piece at a time	3D-printed lightweight cement composite	Laboratory prototype	Wang et al., 2022
Diabolical ironclad beetle (*Phloeodes diabolicus*)	Jigsaw-shaped elytra seam that peels apart layer by layer instead of snapping	Joints between stiff, brittle materials; aerospace-type fasteners	Prototype tested against an existing engineering joint	Rivera et al., 2020
Namib desert beetle (*Stenocara* / *Physasterna*)	Alternating water-attracting bumps and water-repelling troughs	Fog harvesting, anti-frost and self-cleaning coatings, oil–water separation	Prototype, with some field testing; biology contested	Parker & Lawrence, 2001; Nørgaard & Dacke, 2010; ScienceDirect, 2024
Flea	Resilin pad in the thorax compressed and released through leg levers	Catapult-type jumping robots	Laboratory prototype	Sutton & Burrows, 2011
Flea beetle	Elastic energy loaded into the hind-leg joint and held by a latch	Latch-and-spring release in jumping robots	Laboratory prototype	Nadein & Betz, 2016; MDPI, 2023
Locust	Semi-lunar processes of hard cuticle and resilin in the femur	Jumping robots that control orientation and landing	Laboratory prototype	Burrows & Sutton, 2012; Advanced Science News, n.d.

Insect	Mechanism mimicked	Engineering application	Stage reached	Reference
Dung beetle (Scarabaeidae)	Rolling, dancing, foraging, stealing, and breeding behaviors	Dung Beetle Optimizer, used in engineering design and drone path planning	In use as software	Xue & Shen, 2023
Tortoise beetles (*Charidotella egregia*)	Fluid moved between cuticle layers changes reflected color; larval shield built from waste	Tunable colour surfaces and low-power displays; self-renewing protective material	Concept	Vigneron et al., 2007; Missouri Department of Conservation, n.d.

The strongest cases are the ones that have been measured more than once. The diabolical ironclad beetle's seam was imaged, modelled, and then rebuilt as a carbon-fiber and epoxy fastener that held up better than the standard aerospace joint it was tested against, which is about as clean a hand-off from insect to industry as this field offers (Rivera et al., 2020). Chitin is further along again, though not because of engineering: chitosan dressings are already made and sold, and the material had a market before anyone framed it as a beetle idea. The Dung Beetle Optimizer sits in a category of its own, because software has no manufacturing step. Code that works on the day it is published is already deployable. Cement is not.

The middle of the field is crowded. Namib-inspired surfaces do collect water, and some have been tested outdoors, but the patterning wears down and a plain mesh fog net, which costs almost nothing, is still what actually hangs on hillsides in Chile and Morocco. The elytron airfoil has flown on small flapping-wing models and on nothing larger. The rotating-segment pattern held together in a printed test block, which is not a wall. Jumping robots jump, and then somebody picks them up and resets them by hand. These are real results and they are also single results, which is a different thing from a technology.

Three obstacles keep reappearing, and they explain most of the gap between the bench and the world. The first is scale. Insects are small, and a feature that behaves one way at a millimeter often stops behaving that way at a meter; surface tension will hold a droplet on a beetle's back and will do nothing at all for an aircraft wing. The second is manufacturing. A weevil grows its helical layers slowly, at body temperature, out of what it eats, and there is no factory process that does the same thing cheaply, so the pattern gets 3D-printed one block at a time for one paper. The third is durability. A beetle repairs itself and only has to last a season, while a coating on a power line has to survive years of grit, sun, and ice with nobody maintaining it, and most patterned surfaces tested so far do not.

None of this makes the work less interesting. It does mean that the honest word for most of this field is promising rather than proven, and that the two should not be reported in the same tone.

THE LIMITS OF BIOMIMICRY

There is a limit to the method itself, and it is easy to miss when the examples are this appealing.

Evolution does not design. It keeps whatever survives, and what survives is shaped by constraints an engineer does not have. A beetle's shell has to grow, molt, repair itself, and be carried around all day by the beetle. None of those requirements apply to a bumper or a turbine blade, so a structure that is excellent for the insect can be an odd compromise for the machine. Optimal for a beetle is not the same as optimal, and copying too faithfully can mean inheriting a constraint along with the solution.

Materials are the other half of it. Insects build from what they can make out of what they eat, at body temperature, in water, and chitin and resilin are remarkable given that. They are still not stronger than steel. An engineer who is allowed to use steel, or titanium, or a synthetic polymer is starting from a better shelf, and quite often the useful thing to take from an insect is the geometry rather than the material it is made of.

Cost is the quiet one. Nothing here has been shown to be cheaper than what industry already uses, and a patterned surface that has to be etched or printed will lose to a coating that can be sprayed, however elegant the beetle behind it. And the mechanism has to be measured before it is worth copying at all. The fog-basking argument is the clearest reminder of that: a story about a beetle can be repeated for twenty years and turn out to be about the wrong beetle. Biomimicry is only ever as good as the biology underneath it.

CONCLUSION

Insects have had a few hundred million years to solve problems engineers are only now naming. The examples here run from airfoils to armor, from frost-free surfaces to jumping robots to an algorithm that thinks like a dung beetle. What they share is a single move: take a structure or a behavior that evolution already tuned, and read it as a design.

It is worth being honest about how far each of these has actually traveled. A few are built and working, and the diabolical ironclad beetle's jigsaw joint has already changed how engineers think about connecting stiff materials. Most of the rest is still in the laboratory: a printed cement block, a single jumping robot, a coating that behaves on a glass slide. Promising is not proven, and none of these should be assumed to be on its way to wide adoption. Each one still has to clear the same three gates before that can be claimed; it has to keep working outside a controlled test, it has to be manufacturable at the size the application needs, and it has to come in cheaper than whatever is being used now. Plenty of good ideas fail on the last one alone. And some of the underlying biology is still contested, as the argument over whether the fog-drinking beetle even fog-basks makes plain. Biomimicry works best when it copies a mechanism that has been measured, not a story that merely sounds good.

Held to that standard, the insect world is still one of the richest catalogs of design we have, and most of it is unread. As the tools to measure and manufacture at small scales keep improving, some of what is sitting on a laboratory bench will make it out into use, and some of it will not, and there is no way to tell which from the paper alone. The work is learning to ask them precisely, and to wait for the answers to be checked.

REFERENCES

Advanced Science News. (n.d.). *Meet TumRo, a jumping robot inspired by beetles*. https://www.advancedsciencenews.com/meet-tumro-a-jumping-robot-inspired-by-beetles/

AerialCore. (n.d.). *Robotic elytra: Insect-inspired protective wings*. https://aerial-core.eu/wp-content/uploads/2021/11/Robotic_Elytra_Insect-Inspired_Protective_Wings_fo.pdf

Arizona State University. (n.d.). *Weevil genius: Exoskeleton research improving materials*. https://engineering.asu.edu/news/weevil-genius-exoskeleton-research-improving-materials/

Burrows, M., & Sutton, G. P. (2012). Locusts use a composite of resilin and hard cuticle as an energy store for jumping and kicking. *Journal of Experimental Biology, 215*(19), 3501–3512. https://journals.biologists.com/jeb/article/215/19/3501/11002/

Frontiers. (2025). *Chitin-based materials for sustainable applications*. https://www.frontiersin.org/journals/materials/articles/10.3389/fmats.2025.1537067/full

MDPI. (2023). Locust-like jumping robot. *Applied Sciences, 13*(7), 4534. https://www.mdpi.com/2076-3417/13/7/4534

Missouri Department of Conservation. (n.d.). *Golden tortoise beetle*. https://mdc.mo.gov/discover-nature/field-guide/golden-tortoise-beetle

Nadein, K., & Betz, O. (2016). Jumping mechanisms and performance in beetles. I. Flea beetles (Coleoptera: Chrysomelidae: Alticini). *Journal of Experimental Biology, 219*(13), 2015–2027. https://journals.biologists.com/jeb/article/219/13/2015/15300/

Nørgaard, T., & Dacke, M. (2010). Fog-basking behaviour and water collection efficiency in Namib Desert Darkling beetles. *Frontiers in Zoology, 7*, 23. https://link.springer.com/article/10.1186/1742-9994-7-23

Parker, A. R., & Lawrence, C. R. (2001). Water capture by a desert beetle. *Nature, 414*(6859), 33–34. https://www.nature.com/articles/35102108

Rivera, J., Hosseini, M. S., Restrepo, D., Murata, S., Vasile, D., Parkinson, D. Y., Barnard, H. S., Arakaki, A., Zavattieri, P., & Kisailus, D. (2020). Toughening mechanisms of the elytra of the diabolical ironclad beetle. *Nature, 586*(7830), 543–548. https://www.nature.com/articles/s41586-020-2813-8

Roundglass Sustain. (n.d.). *Tortoise beetles: Armor and adaptation*. https://roundglasssustain.com/photo-stories/tortoise-beetles/

ScienceDirect. (n.d.). *Chitin*. https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/chitin

ScienceDirect. (2024). *Bioinspired hydrophobic surfaces for W/O emulsion separation*. https://www.sciencedirect.com/science/article/abs/pii/S2213343724028057

Sitorus, P. E., Park, H. C., Byun, D., Goo, N. S., & Han, C. H. (2010). The role of elytra in beetle flight: I. Generation of quasi-static aerodynamic forces. *Journal of Bionic Engineering, 7*(4), 354–363. https://link.springer.com/article/10.1016/S1672-6529(10)60267-3

Stuttgart University. (n.d.). *Building materials like insect exoskeletons*. https://www.beschaeftigte.uni-stuttgart.de/en/news/Building-materials-like-insect-exoskeletons/

Sutton, G. P., & Burrows, M. (2011). Biomechanics of jumping in the flea. *Journal of Experimental Biology, 214*(5), 836–847. https://journals.biologists.com/jeb/article/214/5/836/33598/

TechXplore. (2024). *Leaf beetles inspire resistant surface design*. https://techxplore.com/news/2024-11-leaf-beetles-resistant-surface-concave.html

Vigneron, J. P., Pasteels, J. M., Windsor, D. M., Vértesy, Z., Rassart, M., Seldrum, T., Dumont, J., Deparis, O., Lousse, V., & Biró, L. P. (2007). Switchable reflector in the Panamanian tortoise beetle *Charidotella egregia*. *Physical Review E, 76*(3), 031907. https://doi.org/10.1103/PhysRevE.76.031907

Wang, W., Chen, S. J., Chen, W., Duan, W., Lai, J. Z., & Sagoe-Crentsil, K. (2022). Damage-tolerant material design motif derived from asymmetrical rotation. *Nature Communications, 13*, 1289. https://www.nature.com/articles/s41467-022-28991-5

Wiley. (n.d.). *Jumping robots inspired by insects*. https://onlinelibrary.wiley.com/doi/10.1002/rob.22427

Xue, J., & Shen, B. (2023). Dung beetle optimizer: A new meta-heuristic algorithm for global optimization. *The Journal of Supercomputing, 79*, 7305–7336. https://link.springer.com/article/10.1007/s11227-022-04959-6