Name: _____ Date: _____

Build, Break, Rebuild: The Physics of Mark Rober

Reading level 13 · 1301 words

At a TEDx talk in April 2018, Mark Rober described the build that had taken him longest: a dartboard meant to give a bullseye every time. The idea, he said, was to track a thrown dart through the air. In engineering terms, a machine like that has three jobs, all in a fraction of a second. It must find the dart, estimate where the dart will land, and put the board in that spot before the dart arrives. Rober said his builds usually take two or three months, but this one took three years. He finished the board, and a video of it appeared in March 2017, a year before the talk, although at one rehearsal, he said, it was barely working. His reaction, as he told it, was a question: what did we learn from that?

Rober's Super Soaker, reported in July 2017 as a Guinness World Record, was seven feet long and fired water at 243 miles per hour. By our arithmetic, that is about 109 meters per second. Rober said the gun had no pump, and pressurized nitrogen pushed the water out of a tank in the handle at 2,400 psi, about eight times the pressure of a firetruck hose, according to a 2018 report. Pressure sets the speed, and speed matters a great deal, because kinetic energy, the energy of motion, increases with the square of the speed. An object that doubles its speed carries four times as much energy. Rober used the gun to break wine glasses, cut a watermelon in half and destroy a soda can.

His six-foot foam-dart gun, recognized in the 2017 Guinness book, answered a different question: how do you store enough energy to throw a foam dart far? Guinness reported that the hard part was harnessing a paintball pressure tank to shoot a dart built from a pool noodle and a toilet plunger. The tank is the energy store, and Rober told NPR in January 2017 that it shoots them 40 miles an hour about 50 yards. The record has since moved, because Guinness now lists a Nerf blaster of 3.81 meters, about twice the length of his, built by another maker in 2021. A larger blaster would change the list again.

Curiosity shows the same physics at a larger scale. It weighs 1,982 pounds on Earth but 743 pounds in Mars gravity, a ratio of about 0.38 by our arithmetic. Airbags could not safely land a rover this heavy, so engineers built a sky crane. A descent stage with eight throttleable rocket engines, four of them controlling the descent, came down at about 0.75 meters per second and lowered the rover on three nylon tethers. About 25 feet below the stage, the wheels touched down, and cable cutters freed the rover. Thrusters work by Newton's third law, because the gas they push down pushes the stage up. Rober was one of more than 3,000 people on the project. He has said he worked on the rover for seven years.

Machines built for a record often succeed by repeating one simple action many times. Dom, the domino robot Rober's team built, places 300 dominoes at a time through funnels and

Connect Four-style slots, and it follows a route programmed in advance, much like a Roomba. Guinness lists the team's record as 6,141 dominoes set up and toppled by a robot in one hour, on 19 July 2021. By our arithmetic, that is about 102 a minute. If every pass placed a full 300, it would mean about 20 passes in the hour, one every three minutes. Press reports of a 24-hour run gave totals near 100,000, and they do not agree with each other.

The glitter bomb, posted in December 2018, can be read as a system built to survive its own failures. Rober said he spent six months engineering it, and reports said he tested different bait-package set-ups. A custom circuit board with an accelerometer sensed movement and checked whether the box had left a geofence, a virtual boundary, around his house. Four Android phones then woke and recorded with wide-angle lenses, and they had LTE data plans and automatic cloud uploads. By our reading, that means the footage could survive even if the box was never recovered. The first video drew 25 million views in one day. Rober posted an improved version in December 2019 and a third a year later.

The squirrel courses show iteration against a living opponent. In 2020 Rober built an eight-part course to keep squirrels from stealing food from his bird feeders. Reports said the squirrels skipped the first obstacle, a ladder bridge, and beat the course after just a few days. A year later he built a bigger course over about two months, designed to test the squirrels' mental limits and physical limits, with a one-way exit door in each room. The 2021 video introduces four squirrels by name, and in the end the squirrels reached the vault. These were videos, not controlled experiments: the squirrels chose whether to try each part.

Failure can also give a designer information he did not ask for, and sometimes it arrives as a surprise. In one of his videos, Nerdist reported, a chemical foam reaction pushed so hard that it ripped the bottom off the structure holding it. A catalyst is a substance that speeds a reaction without being used up. Newton's third law says that whenever one object exerts a force on a second object, the second exerts an equal and opposite force on the first. By our reading, that is the same law that holds up a sky crane: material pushed out one way pushes the structure the other way, and a structure that cannot take that push comes apart.

Rober gave his approach a name, the Super Mario Effect: focus on the princess, not the pits. His evidence was an experiment on about 50,000 of his YouTube followers. By our arithmetic, that is roughly 1.7 percent of the three million he had at the time. Each person was randomly shown one of two versions of a coding puzzle, and in one version a failed run cost five of 200 starting points. According to a transcript of the talk, about 52 percent of the penalized group solved the puzzle, against 68 percent of the group with no penalty, and Rober called that 16-point gap statistically significant. Because the people chose to play, the result describes that group. It was presented in a talk, not a journal.

The path that led here has dates. Rober earned a mechanical engineering degree in 2004 and joined the Jet Propulsion Laboratory the same year, spending seven of his nine years there

on Curiosity. In August 2012 he posted a video about what it felt like to watch the rover land. He had made his first YouTube video in October 2011, while still at the lab. In 2021 a British engineering institution gave him a prize as STEM Personality of the Year. In 2023 he gave the commencement address at MIT, where the school's page records his advice to practice optimism combined with dedication. By our reading, the advice fits a career built from tests.

What the builds share can be stated plainly. A gun became a record that someone else passed. A robot turned one repeated action into a large total. A trap went through three versions, and two squirrel courses fell to the squirrels. A dartboard worked, but it took three years instead of three months. In each case, by our reading, the design met a test, the test gave a result, and the result changed the next version, a loop of build, test, learn and repeat. Rober's own question for a failure, as he told it in 2018, was short: what did we learn from that?

Questions

1. By this book's arithmetic, about how fast is 243 miles per hour in meters per second?

A. About 54
B. About 109
C. About 243

2. Why does doubling a jet of water's speed matter so much?

A. Water becomes heavier
B. The gun gets longer
C. Kinetic energy grows with the square of speed

3. Why did the Curiosity landing use a sky crane?

A. Airbags could not safely land a rover that heavy
B. Parachutes do not work on Mars
C. The rover could fly

4. In the sentence "A catalyst is a substance that speeds a reaction without being used up," what does speeds mean here?

A. Slows down
B. Makes faster
C. Keeps the same

5. Why does the book say the Super Mario Effect result describes only one group?

A. The puzzle was too hard for most
B. The talk was a journal paper
C. The people chose to play, so they are one group

6. What does the book say happened to Rober's Nerf gun record?

A. Another maker's larger blaster was listed in 2021

B. It was never recognized

C. It was broken in 2017

Words to know

kinetic: of motion

geofence: virtual boundary

catalyst: reaction speeder

tethers: cords

accelerometer: motion sensor

iteration: repeated improvement

Answer key: Build, Break, Rebuild: The Physics of Mark Rober

1. B. About 109
2. C. Kinetic energy grows with the square of speed
3. A. Airbags could not safely land a rover that heavy
4. B. Makes faster
5. C. The people chose to play, so they are one group
6. A. Another maker's larger blaster was listed in 2021