Erik Basil Spooner **ART DIRECTOR** + **DESIGNER**

Seemingly random attacks contain an unexpected regularity: the same numerical pattern seen in Wall Street booms and busts.

mathematics of terror

By Andrew Curry

Illustrations by Tavis Coburn

Since the 1960s, the mountains of southern Colombia have been home to a war between the government and a leftist guerrilla movement known as the Revolutionary Armed Forces of Colombia, or FARC. The conflict has simmered for decades. Sometimes it flares up in battles with government forces, a terror bombing, or a particularly high-profile kidnapping. Sometimes it fades into the background as cease-fires or negotiations quiet the hostilities. FARC has been fighting for so long that the war has become almost like background noise, says Neil Johnson, a University of Miami physicist who travels to Colombia every year to visit his wife's family. Even locals have become numb to the conflict. "There's this war going on, but I didn't think too much of it. You hear numbers of dead every day, like football results," Johnson says. "It took me 10 years to realize that maybe there was important information hidden in those numbers."

Johnson, who specializes in the study of complexity, is one of a new breed of physicists turning their analytical acumen away from subatomic particles and toward a bewildering array of more immediate human problems, from traffic management to urban planning. It turns out that subatomic particles and people are not that different, he explains. "The properties of individual electrons have been known for many years, but when they get together as a group they do bizarre things"—much like stock traders, who have more in common with quarks and gluons than you might think. So profound is the connection that quants (quantitative analysts, often with backgrounds in physics or engineering) have flocked to Wall Street, creating elaborate models based on the way markets have moved in the past. Arrlix, a clearinghouse for physics research papers, includes an entire section on "quantitative finance."

Still, it was not until a chance 2001 meeting in Bogotá with Mike Spagat, an economist at Royal Holloway College, University of London, that Johnson considered modeling something as human as warfare. Spagat had a Colombian Ph.D. student named Jorge Restrepo who was gathering data on attacks and death tolls, provided by the nonprofit Center for Investigation and Popular Education, so he could look for patterns in the conflict. Johnson hoped the numbers could tell them something about how the individual particles—in this case, insurgents rather than electrons—functioned when put together in large groups.

Soon the new team had a database that included more than 20,000 separate incidents from two and a half decades of FARC attacks. Johnson and Spagat expected that the success of the attacks, measured in the number of people killed, would cluster around a certain figure. There would be a few small attacks and a few large ones as outliers on either end, but most attacks would pile up in the middle. Visually, that distribution forms a bell curve, a shape that represents everything from height (some very short people, some very tall, most American men about 5'10") to rolls of the dice (the occasional 2 or 12, but a lot of 6s, 7s, and 8s). Bell curves are called normal distribution curves because this is how we expect the world to work much of the time. But the Colombia graph looked completely different. When attacks and people killed were plotted out, the result was a line that sloped gently across the top of the graph before plunging sharply down, like a backward r. At the top were lots of tiny attacks; at the bottom were a handful of huge ones.

That pattern, known as a power law curve, is an extremely common one in math. It describes anything that increases or decreases exponentially. With power law curves there is no clustering. Instead there is a steady progression defined by a power, or exponent, as in two to the power of two (2 x 2) equals four, three to the power of two (3 x 3) equals nine, four to the power of two (4 x 4) equals 16, and so on. If the height of Americans were distributed according to a power law curve rather than a bell curve, there would be 100 million people standing 7 inches tall, 60,000 people towering at 8'11", and a solitary giant as tall as the Empire State Building. Although power laws clearly do not apply to human height, they show up often in everyday situations, from income distribution (billions of people living on a few dollars a day, a handful of multibillionaires) to the weather (lots of small storms, just a few hurricane Katrinas).

In Colombia's case, decades of news reports confirmed that the number of attacks formed a line that sloped down from left to right. In general, an attack that causes 10 deaths is 316 times as likely as one that kills 100. The larger the event, the rarer it is.

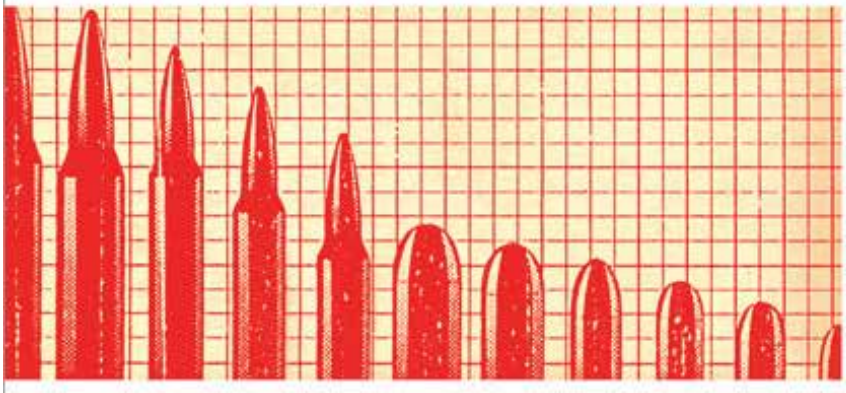
At first the pattern seemed too clear and simple to be true. "Immediately I thought, 'We need to look at another war,'" Johnson says. With the U.S. invasion of Iraq in full swing, he and his collaborators had an obvious second test. In 2005, using data gleaned from sources like the Iraq Body Count project and iCasualties, a Web site that tracks U.S. military deaths, they crunched the numbers on the size and frequency of attacks by Iraqi insurgents. Not only did the data fit a power curve, but the shape of that curve was nearly identical to the one describing the Colombian conflict.

Around that time, a Santa Fe Institute computer scientist named Aaron Clauset was applying the same approach to what seemed like a distinctly different problem. Rather than looking at specific guerrilla movements, Clauset was examining total deaths caused by global terrorist attacks since 1968. When he plotted nearly 30,000 incidents on a graph, they formed a curve to the power of –2.36. (The power number is negative because it reflects a decrease rather than an increase in the number of events as death tolls rise.) With its sharp downward slope, the curve was eerily similar to those generated by Johnson and Spagat for Colombia and Iraq.

To rule out coincidence, Johnson, Spagat, and University of Oxford physicist Sean Gourley gathered data on nine other insurgencies. One after another, the curves clicked into place. Peru's Shining Path guerrilla movement: a curve with a power of –2.4. The Indonesian campaign against rebels in East Timor between 1996 and 2001: –2.5. The Palestinian second intifada: –2.55. Fighting against Afghanistan's Taliban between 2001 and 2005: –2.44. By contrast, traditional conflicts in which two armies squared off against each other (such as the Spanish and American civil wars) did not yield power curves; the graphs were flatter, indicating equal numbers of battles of different sizes. Although the politics, religion, funding, motives, and strategies of the insurgencies varied, the power trends did not.

In an age of biological weapons and dirty nukes, the implications are chilling. Although truly massive power-law events—like the Great Depression or killer storms—are exponentially less common than smaller disruptions, they still occur. One might use the math to argue that the 9/11 attack that killed more than 2,800 people in New York City was bound to happen. And there is ample reason to believe that an even bigger one is on the way, sooner or later.

For Johnson, a Cambridge- and Harvard-educated physicist who has studied stock markets and other apparently



When the attacks and the number of people killed were plotted out, the line sloped gently across the top before plunging sharply down.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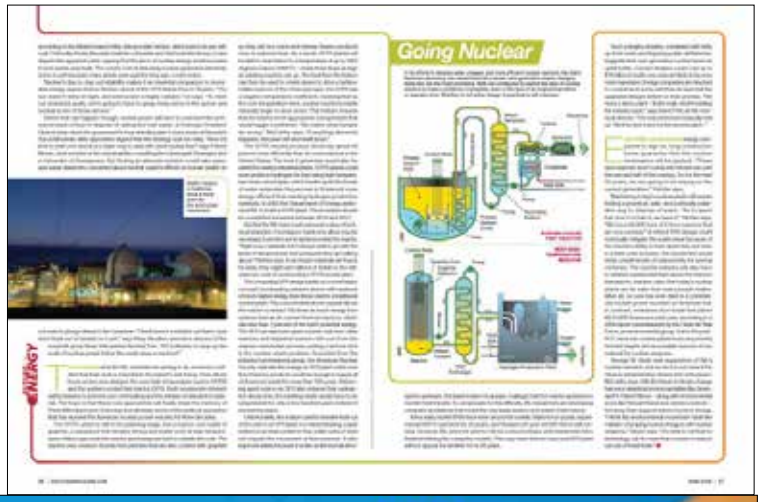
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DREAM CHASERS

As NASA steps down from spaceship and rocket development, the private sector is stepping up. Can business revive the old spirit of adventure?

BY DAVID H. FREEDMAN

There is a bright blue sky over Denver, and Mark Sirangelo is eager to fly. A 50-year-old engineer with short black hair, a buttoned gray shirt, and dark slacks, Sirangelo strides into a small hangar just outside downtown. A few helicopters wait inside, including a cherry-red one that looks like something out of a giant Lego set. But Sirangelo has not come for any of these. He heads to a strange, white-and-black ship parked in the corner, one that looks like a giant prop from a science fiction movie. Measuring about 30 feet long by 20 feet wide, it has two sweeping wings near the back and a wide, curving window over the nose. The words "Dream Chaser" are printed on the side in sky blue near a golden arc, an American flag, and a NASA logo. The big ship is so odd that when Sirangelo nears, a tanned pilot at one of the copters drops what he's doing and jogs over to ask what the heck it is. "It's a spacecraft," Sirangelo replies with an evasive smile.

At that smile-laden, his answer is truthful but wildly incomplete. The Dream Chaser is the creation of the Sierra Nevada Corp., an electronic systems manufacturer in Sparks, Nevada. For more than 20 years, the company's space exploration department has helped build technologies ranging from handheld rocket motors to communication satellites. Under the guidance of Sirangelo, it is now taking on a far more ambitious project. By 2014 the Dream Chaser could make its first orbital flight, and shortly thereafter it could be routinely ferrying up to seven people into low Earth orbit—on a visit to the International Space Station, for instance.

That is where the NASA logo on the side of the ship comes in. The Dream Chaser is the most tangible product of the space agency's controversial new mission: privatizing space exploration. Ever since its birth in 1958, NASA has been synonymous with America's manned space program, from the triumphs of the Apollo missions to the disasters of the space shuttles Challenger and Columbia. That all changed in February, when President Obama proposed an end to the $100 billion Constellation program, whose goal was to create the spacecraft and rockets needed to take humans back to the moon and beyond. With the space shuttle program already slated to wind down by early 2011, NASA will soon have no ability to send humans into space on its own. Instead, it is turning to entrepreneurs like Sirangelo to do the job.

To stimulate the nascent private space industry, Obama has requested that $6 billion of NASA's budget over the next five years be diverted to space tech development. Earlier this year, Charles Bolden, NASA's administrator, put a small but symbolically significant bet on the table, awarding $50 million from the American Recovery and Reinvestment Act of 2009 (better known as the stimulus act) to private spacecraft developers, whom he called "the faces of the new frontier." These faces run from established players like Boeing to fresh start-ups like Blue Origin, launched by Amazon.com founder Jeff Bezos. Sierra Nevada was a big winner, receiving $20 million for the Dream Chaser project. The Obama plan is to create a diverse industry of taxi fleets that will transport cargo and crew to low Earth orbit, both for NASA and for commercial enterprises such as satellite companies or space tourists.

The administration's move has sparked a battle not just for contracts but for the soul of the space program. NASA sees privatization as crucial to addressing the chronic mismatch between the agency's grand plans and its modest budget. "At NASA we need to focus our resources and priorities on conquering the hardest challenges in space—moving out to the moon, Mars, and the rest of the solar system," says Alan Lindenmoyer, Commercial Crew and Cargo program manager at the Johnson Space Center in Houston. "This is a great opportunity to count on the skills of American ingenuity to take on the task of routine access."

But many politicians and pundits do not trust that private companies can get the job done safely and effectively. These concerns range from the technological challenges to the economics of putting people into space. If NASA downsizes, where will the money come from to finance the development of a whole new industry? And if other customers do not materialize, can NASA alone keep that industry afloat? The attacks have been especially swift and sharp from senators Barbara Mikulski (D-MD) and Richard Shelby (R-AL), who represent states that currently get substantial NASA investment, as well as from former Apollo astronauts Neil Armstrong and Eugene Cernan. Armstrong called the Constellation cancellation "devastating." More surprising, even major aerospace companies have expressed doubt. John Karas, vice president and general manager of human spaceflight at Lockheed Martin, recently declared, "I don't think there is a business case for us."

"I don't believe this was the right way to go at this time, as it places an incredible amount of pressure on private companies," says Scott Pace, director of the Space Policy Institute at George Washington University in Washington, D.C. "They say they're up to it, and I hope they are, but government policy should not be to release on private business plans."

And yet Sirangelo continues to smile. He is not worried about the pressure to succeed. From his point of view, he is already doing it.

Sirangelo's dream began in 2004, when President George W. Bush announced that NASA would be phasing out the space shuttle program at the end of the decade. In that plan, however, the next-generation rockets and space capsules (which evolved into the Constellation program) would not be ready until 2015. The gap meant that the United States would soon—for the first time in three decades—have no spacecraft that could move people and cargo into Earth orbit. Relying solely on Russian Soyuz spacecraft to fly Americans to the International Space Station would be expensive—and tenuous, should relations with Russia ice over. "We all knew the shuttle would stop flying, but what wasn't clear was the solution," Sirangelo says.

Sirangelo, who began his aeronautical journey as a crop duster, spent a year combing for answers. Then he found a file buried in NASA's public records. In the early 1960s, he read, an Australian pilot spotted something unusual floating in the Indian Ocean. The pilot snapped a few photos, which revealed a Russian transfer hosting a small, futuristic craft out of the water. The grainy black-and-white pictures eventually wound up in the United States, where officials knew exactly what it was: the BOR-4.

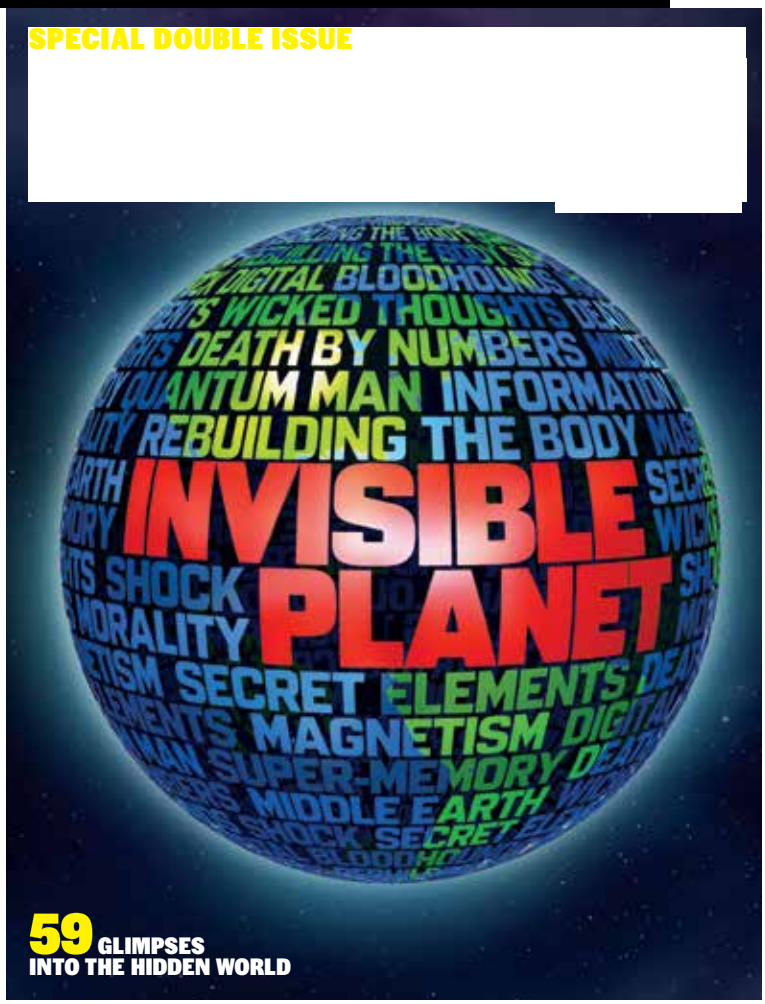
BOR-4 is a Russian acronym for unpiloted orbital rocket plane; the Russians built the experimental craft in response to the then new U.S. space shuttle program. In a bit of one-upmanship, NASA's Langley Research Center in 1960 began developing the HL-20, a craft that could take off and land horizontally and reach low Earth orbit. Such vehicles, capable of making multiple flights, are called reusable lifting bodies (a lifting body being a craft that generates lift from its fuselage rather than from wings). "NASA was looking at the HL-20 as a candidate for a crew rescue vehicle," Lindenmoyer says. "At one point we considered it a possible replacement of the shuttle."

This idea was shelved after nearly 10 years of development, and NASA agreed to use the Russian Soyuz capsule as the rescue vehicle for the space station. But now, reviewing NASA's records, Sirangelo thought that the HL-20's time had come. In addition to having the reusability and features of a small space shuttle, the craft already had two decades of research and development behind it. Moreover, the HL-20 was able to move quickly from orbit to a gentle touchdown, meaning that it should be both inexpensive and flexible. Sirangelo saw that he could create a new design, inspired by NASA's innovations of the past but built for the private future.

He needed a name, and that came to him quickly: the Dream Chaser. "We were chasing our dreams," he says. "What we're trying to do is manifest for ourselves that it is possible to do something like this. You don't have to be a major global corporation. A group of talented people working hard and using creativity could follow their dream and make this work out."

Painfully aware of the looming break in America's space capabilities, NASA had already begun making plans to seed the commercial spaceflight business. In 2006 it ran a $500 million competition to develop cargo transport solutions for servicing the International Space Sta-

The Dream Chaser spacecraft launches atop an Atlas V rocket in this artist's rendering.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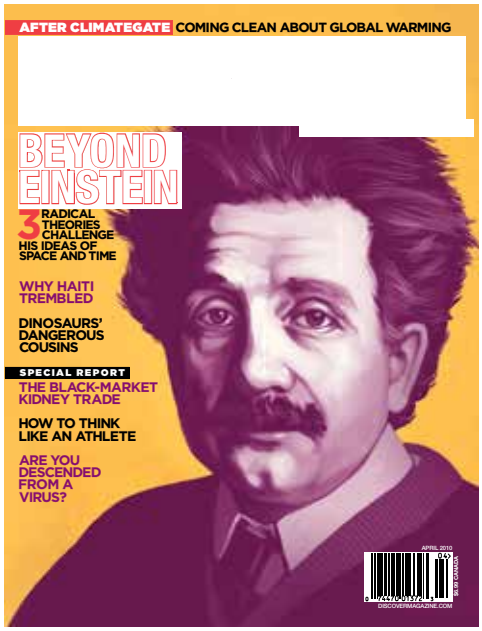
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