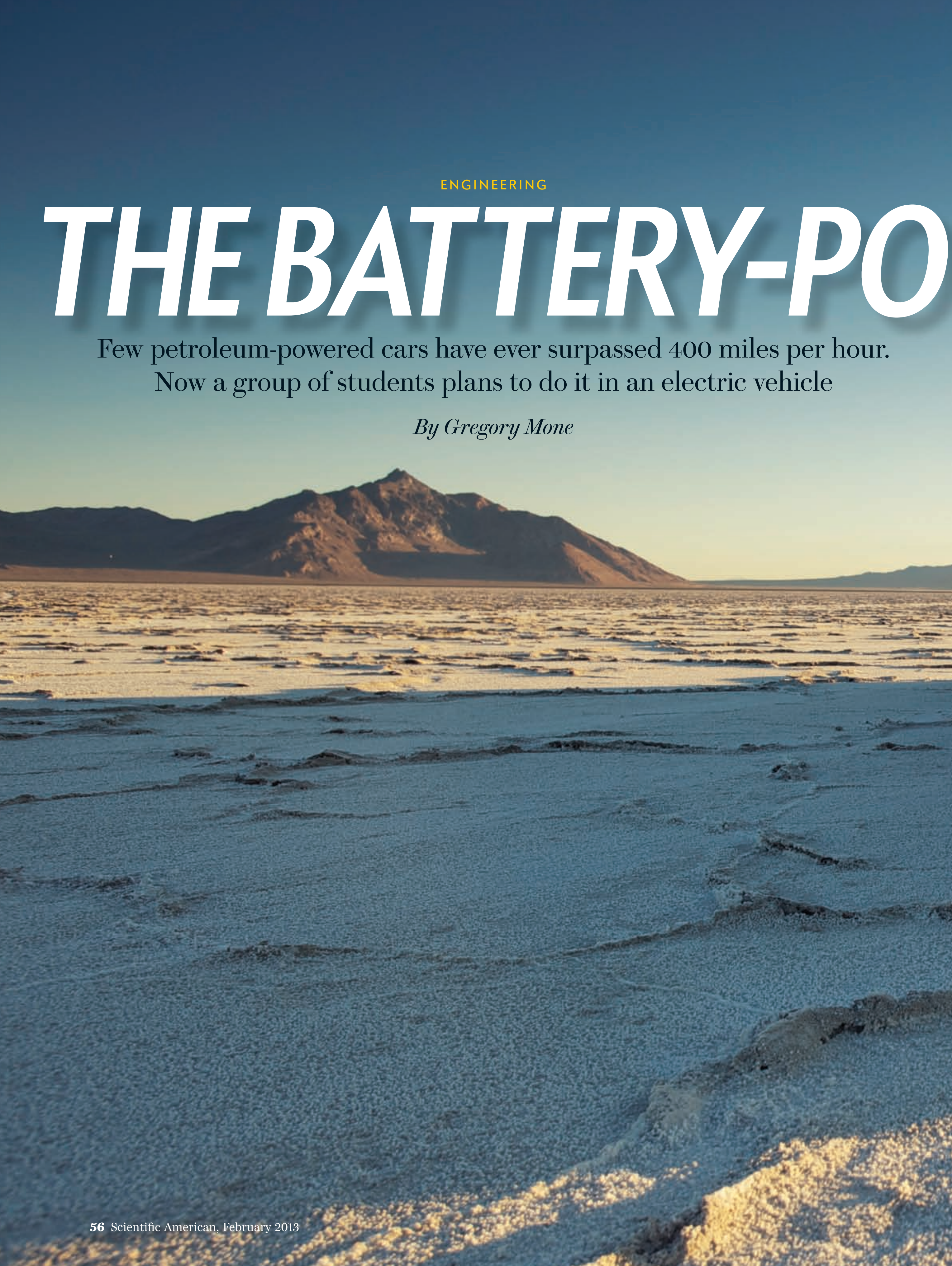
ENGINEERING

THE BATTERY-PO

Few petroleum-powered cars have ever surpassed 400 miles per hour. Now a group of students plans to do it in an electric vehicle

By Gregory Mone



WERED BULLET

ELECTRIC FLASH: **The Buckeye Bullet 2.5 hit 307 miles per hour on Utah's Bonneville Salt Flats in 2010.**

Gregory Mone writes about science and technology for publications that include the *Atlantic, Discover* and *Popular Science*. He is also the author of four books.

AS HE WAS WALKING TO A MATH CLASS DURING HIS freshman year at Ohio State University, R. J. Kromer spotted a poster for a student-run team designing a fuel-cell-powered car. He had never built anything more complex than Lego-based robot kits, but he sent an e-mail to the group asking to join anyway. To his surprise, the team members responded immediately. "I thought there would be all kinds of requirements," Kromer recalls, "but they said, 'No, just show up.' "

So Kromer headed over to the team's work space at the school's Center for Automotive Research (CAR). He quickly learned that the unique tribe of mostly baby-faced engineers behind the Buckeye Bullet vehicles, a series of world-record-breaking alternative-fuel cars, planned to test his dedication first. Kromer started out in the engineering equivalent of the mail room. For the first few months he was mostly sweeping the shop or arranging and organizing various tools and spare parts. Between custodial tasks, though, senior team members started teaching him about wiring, control systems, and more. Soon he was learning more in the shop than he was in class. The next year two seniors graduated, and Kromer was in charge of electrical engineering. "It turns out if you're willing to not sleep, you can pick up on things pretty fast," he says.

The Buckeye Bullet team is filled with similar stories. Team leader David Cooke joined by chance as a freshman. Senior engineer Evan Maley joined as a wide-eyed high school student who liked fast cars. Cooke says that in evaluating new volunteers, the team does not look for IQ scores so much as a willingness to work. Kromer's voluntary insomnia is a group hallmark. Bullet engineers often watch dawn creep in below the 30-foot-tall garage bay doors at the end of their shop. They sleep on conference room floors and, occasionally, test tracks. They spurn the average student's beer-doused weekend in favor of cutting metal, testing batteries and designing custom suspension systems.

These are not suspension systems on go-karts. This group has produced several of the fastest alternative-fuel vehicles in history. The hydrogen fuel-cell car that drew Kromer's interest averaged a top speed of 286 miles per hour in 2008. Two years later the team remodeled it into a battery-powered racer that surpassed 300 mph. And in September of this year, on the Bonneville Salt Flats outside Wendover, Utah, the group contends that its redesigned vehicle will be the first electric racer to crack 400 mph.

Only nine gasoline-powered, wheel-driven cars have ever gone that fast. "The jump from 300 to 400 is huge," Cooke says. As the car approaches 400 mph, aerodynamic drag increases geometrically. The motors demand more current, which means more batteries and added weight in a vehicle that needs to be as light as possible. Finally, the tires will spin so fast that centrifugal forces threaten to rip them apart. The challenges are

IN BRIEF

The Buckeye Bullet team at Ohio State University is building what it hopes will be the first electric vehicle to break 400 miles per hour, something only nine gas-powered cars have done.

Earlier iterations of the vehicle have already set electric-vehicle speed records, but crossing to 400 mph requires that the team invent solutions to a host of engineering problems.

Among the challenges: generating enough power from the four electric motors, tweaking the aerodynamics to keep the car fast but stable, and making sure the tires don't blow apart.

If all goes as planned, the team will make its attempts at breaking the 400-mph barrier during test runs this coming September on Utah's Bonneville Salt Flats.

PRECEDING PAGES: COURTESY OF BARRY HATHAWAY AND THE CENTER FOR AUTOMOTIVE RESEARCH, OHIO STATE UNIVERSITY formidable enough to discourage a team of veteran engineers, let alone a band of grad students and college kids.

FAST DESIGN

IN 1993 GIORGIO RIZZONI, now director of CAR, assembled the first student team to compete in a short-lived collegiate racing series for battery-powered cars. The team's vehicle, the Smokin' Buckeye, won most of its races, but within a few years the series was cancelled, and Rizzoni figured that would be the end of the program. Instead two of his students informed him that they had struck a sponsorship deal with a local company. They wanted to build the fastest electric car in history. "I looked at the students and said, 'You are positively insane,'" Rizzoni recalls.

Over the next decade the team built three world-record-breaking vehicles. Now Rizzoni rarely questions the team members' lofty goals or engineering or deal-making skills. When Cooke and the team decided they wanted to break the 400-mph barrier, they knew they would need to veer off the standard funding avenues. So they appealed to Gildo Pallanca Pastor, the then 45-year-old owner of Venturi Automobiles, an electric vehicle manufacturer based in Monaco. Pastor, a former amateur racer, the head of a Monaco real estate empire and a restaurateur, had been tracking the team for several years. In 2010 he signed a sponsorship deal to back the quest for 400 mph.

Two years later, on a humid Wednesday last August at CAR headquarters, an inauspicious two-story building with a brick facade at the front and several cavernous hangars at the back, the bearded, 26-year-old Cooke explains that the overall design of the car is nearly settled. The Venturi Buckeye Bullet 3 (VBB3) will be 38 feet long, with four-wheel drive. Because the power required to accelerate the car to 400 mph would be too great for one motor, the team plans to divide the task among four of them. Each motor will generate 400 horsepower, 1,600 in total.

Cooke and several others have been collaborating with Venturi engineers on a custom motor design. The Bullet engineers outlined the ideal dimensions, performance specifications and other details, and they have been iterating designs with the Venturi team for a year. Pastor has already begun road testing a scaled-down version of the Bullet's motor in Venturi's America model, an electric sports car with a top speed of 124 mph. The four Bullet motors will be slightly longer and more powerful, but they will not be finished for a few weeks.

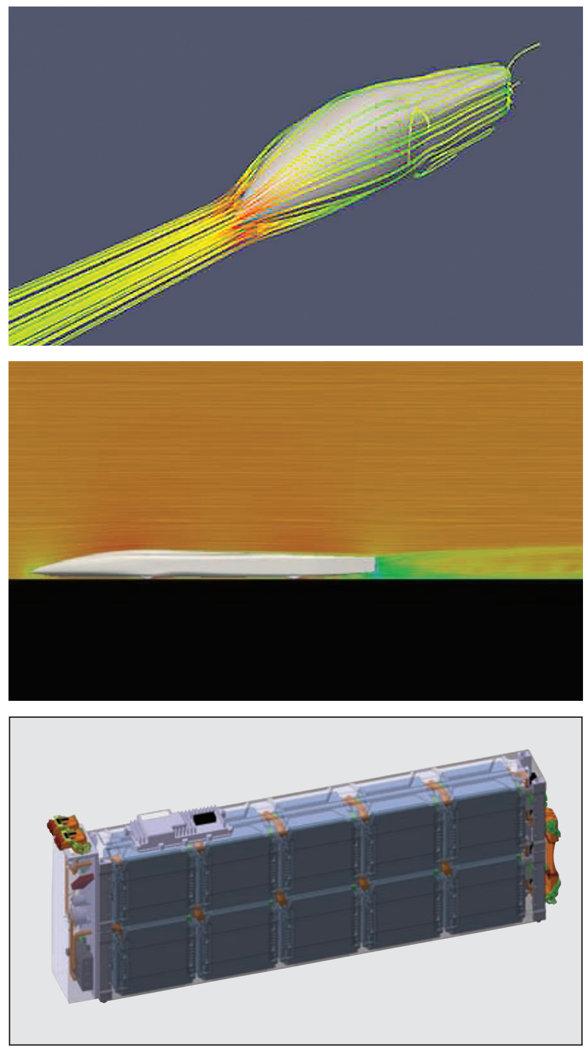
For now, though, the motors are not the main concern. At CAR, the graduate and undergraduate students on the VBB3 team, including Cooke, Maley and a dry-witted 23-year-old engineer named Ling Wang sit in the same small office. When Maley and Cooke step inside, Wang is flipping around a 3-D model of the car's vertical tail fin on his screen. Wang is the aerodynamics expert, and aerodynamics is arguably the biggest challenge in jumping from 300 to 400 mph. The power required to overcome aerodynamic drag is proportional to the cube of the desired velocity. So if you want to double your speed, you need roughly eight times the power.

Cary Bork, a former team member who had just left to take a job at Boeing, spent two years fine-tuning the VBB3's aerodynamic shell, changing the shape and adding drag-reducing features such as spoilers to cover the wheels. The Bullet will have a steel frame and a carbon-fiber shell with a strong but lightweight core made in part from Nomex, a flame-resistant fiber.

COMPUTER SIMULATIONS

The Shape of Speed

When race cars go into wind tunnels, the designers place a rotating belt under the vehicles to accurately model the interaction between the car and the ground. But most belts only work up to 150 mph. So the Buckeye Bullet team is doing all of its aerodynamic modeling using computational fluid dynamics (*top* and *middle*). The narrow design of the new Bullet is made possible by flat "pouch" battery modules (*bottom*).



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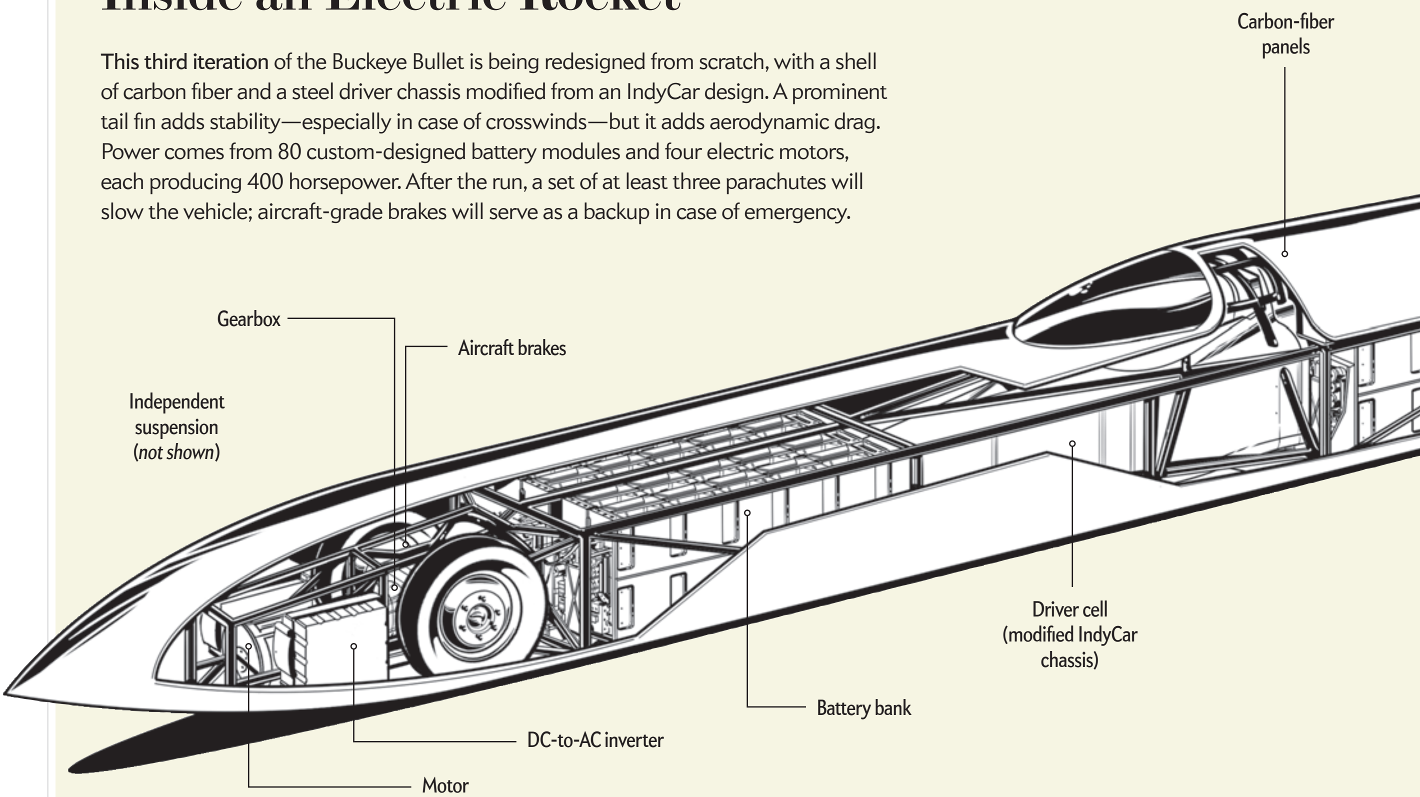
Yet a few big questions remain. Today Wang is focused on the tail fin.

Anything that juts out of the car will add drag, but the team has to have a tail fin to protect the safety of the test driver, a 62-year-old racer named Roger Schroer. All the aerodynamic forces acting on a vehicle can be averaged to a single point, known as the center of pressure. When this point is toward the rear and the vehicle's center of mass is closer to the front, the two balance each other out and keep the vehicle on a straight-line course even with a side wind. The VBB3 will have multiple parachutes and, as a backup, a set of aircraft brakes, but neither

Inside an Electric Rocket

This third iteration of the Buckeye Bullet is being redesigned from scratch, with a shell of carbon fiber and a steel driver chassis modified from an IndyCar design. A prominent tail fin adds stability—especially in case of crosswinds—but it adds aerodynamic drag. Power comes from 80 custom-designed battery modules and four electric motors, each producing 400 horsepower. After the run, a set of at least three parachutes will slow the vehicle; aircraft-grade brakes will serve as a backup in case of emergency.



would help Schroer in the event of a spin. "At the end of the day," Cooke says, "Roger's life is the most important thing."

The question is how to strike a balance between aerodynamics and safety. With rapid mouse clicks, Wang picks apart the tail and spins it around in the virtual 3-D space. He switches from a flat design that comes to a point at the top to something resembling the end of a dolphin's tail—a horizontally oriented fin mounted atop an otherwise vertical one. Maley explains that the team is trying to figure out a way to add a GPS unit and two cameras—one facing the front, the other looking back—to capture data during the run. Wang added the horizontal fin to house all three, then sent his revision to Bork at Boeing.

The new addition, Wang informs them, has just been "Borked." This is the team's shorthand for when Bork rejects a change on the grounds that it will add too much drag. "He's telling us, 'You're making the car go slow, so don't do it,'" Cooke explains.

Slightly annoyed, Wang clarifies: "I knew it was going to make it slower," he says. "But how much slower?"

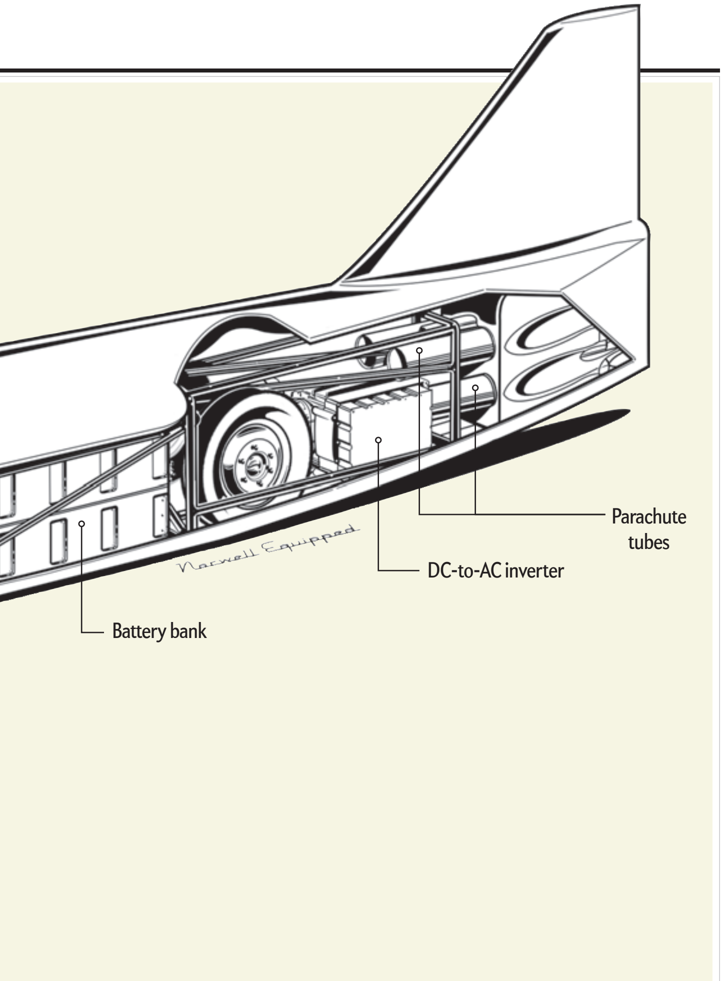
As Wang goes back to the model, Cooke turns to another challenge, the batteries. Earlier in the day he showed off several of CAR's battery-testing chambers. Inside, custom programs repeatedly deplete and charge up battery cells, all while modulating the environmental conditions. This gives CAR's engineers a better sense of a battery's true performance, which does not always match the advertised specifications. For the past year Cooke and the group have been rigorously testing a prototype iron nanophosphate lithium-ion battery from the now defunct manufacturer A123 Systems. On race day, the Bullet will have to finish at least two runs to earn an official world record, and at the end of each 60-second sprint, Cooke notes, the batteries need to be completely depleted. "We want to get all the energy out of a battery in one run," he says. "If we leave any extra energy in, that means we carried extra weight in batteries."

The A123 batteries, designed in part by two former Bullet team members who worked at the company, not only store more charge than anything else on the market, they also do it in a tighter package. Cooke explains that standard cylindrical cells, such as the ones they used on their last racer, take up too much space. The circular cross section leaves gaps when you pack them together. That added space translates into more overall volume and a larger car, which means a thicker aerodynamic profile and, in the end, less speed.

Cooke takes a black box reminiscent of a car battery down from a shelf next to his desk, along with a thin, flat, silver square package that could pass for an ice pack. These pouch-type batteries generate more current from a smaller volume. Each one of the black modules will hold 25 pouch cells, with one packed next to the other without gaps, and the savings relative to cylindrical batteries will be enormous, given that there will be 80 of these modules in all. "You're cutting off a third of the weight and volume," Cooke says. "This is above and beyond the best that's out there."

This challenge of packaging extends beyond the batteries. The vehicle design process is largely about cramming as much

 Illustration by Jeff Norwell



as possible into as narrow a space as possible. Across from Cooke's workstation, for example, Maley's monitor displays a virtual rendition of the suspension system. Record-breaking speedsters often forgo suspension to save weight. Because the driver will have only one mile to accelerate the vehicle, however, Maley and the team decided that they will need traction over every inch of that mile. A bump in the salt flats that causes the wheels to spin, even momentarily, could result in a loss of precious power. Maley explains later that the shocks for the suspension were originally going to be set below the motor and transmission. He is now in the process of revising that design. After considering the overall packaging, he saw that the shocks would have shifted the vehicle's center of gravity upward. "When you think about the transmission and motor weights, you're talking about a few hundred pounds," he says. "You want to keep that weight as low as possible for stability."

Next, Cooke heads out to the shop, a long, open warehouse that also houses various other student-run CAR projects. At the Bullet's station, Cooke grabs a tire with just one-sixteenth of an inch of rubber. He explains that as the vehicle passes 300 mph, the tires will spin so fast that centrifugal force will cause them to expand. The more rubber, the more mass and the greater the force trying to rip that mass apart. A thinner tire means less mass and less chance of the tire disintegrating at high speeds. The catch is that the vehicle will be cruising on a fairly rugged salt flat. "Will the tires make it?" Cooke asks aloud. "That's one of the things that keeps me up at night."

COUNTDOWN TO LAUNCH

THREE MONTHS LATER, in early November, the team is just two months from beginning construction. Maley has redesigned the suspension to lower the motors and the car's center of gravity, but the tail remains a point of debate. As a safety precaution, the team is now considering including three or even four braking parachutes. These extras risk making the rear of the vehicle too large, increasing drag. "The number of parachutes is floating right now," Wang admits.

A month before, the battery supplier A123 had gone bankrupt, but luckily the company's Bullet alumni pushed the project's batteries out the door. "We have all our stuff from them, plus some spares," Cooke says.

The motors are also complete, albeit in slightly revamped form. After further simulation tests, Venturi engineers suggested the motors might not be able to provide enough power. Cooke was hardly discouraged, though. "We've learned that you can't just accept no," he says. "You need to ask why. Why can't we pull any more power? Is it that you can't physically run any more current through the copper windings?" Further digging revealed that the problem was, in fact, related to temperature. According to the simulations, the motors were going to overheat. So Cooke, Maley and fellow undergraduate Luke Kelm worked with Venturi to redesign the motor's cooling system. They changed the flow of the oil-based coolant so that it will come into contact with the motor at more points, thereby enabling it to draw out more heat and keep the temperature down.

This is the legacy of the Bullet project: less a set of technological innovations, impressive though they may be, than a commitment to understanding the limits of existing technology to overcome them. "It's a fantastic exercise," Venturi's Pastor says. "When you have to push components to their limit, you can discover new things and push your ideas in a different way."

Ultimately these challenges provide an unparalleled education, producing a uniquely experienced set of graduates. The Bullet program has produced 50 engineers over the years, and most have gone on to prime jobs in the automotive manufacturing, aerospace and battery-technology sectors. "They are better engineers because they have dealt with these complex problems," Pastor notes.

Kromer, the former freshman who joined on a whim, says he has earned an education that goes far beyond what he learned in class. The kid who did not know a thing about cars has spent the past two years designing the electronic brains of the vehicle, a system that monitors the performance of every component and syncs it all with the driver's controls. Still, Kromer and the others are not just doing it for the lessons. At their core, they are still college kids, and the prospect of breaking that 400-mph barrier in September looms large. "We could break an international speed record," he says. "How many people coming out of college get to say that?" SA

MORE TO EXPLORE

Driving to Mach 1. Gary Stix in *Scientific American,* Vol. 277, No. 4, pages 94–97; October 1997.

The Buckeye Bullet: **www.buckeyebullet.com**

SCIENTIFIC AMERICAN ONLINE
Watch the previous iteration of the Buckeye Bullet break 320 miles per hour at **ScientificAmerican.com/feb2013/bullet**