Golf: The Final Frontier

The design engineering and material science behind the latest revolution in golf equipment

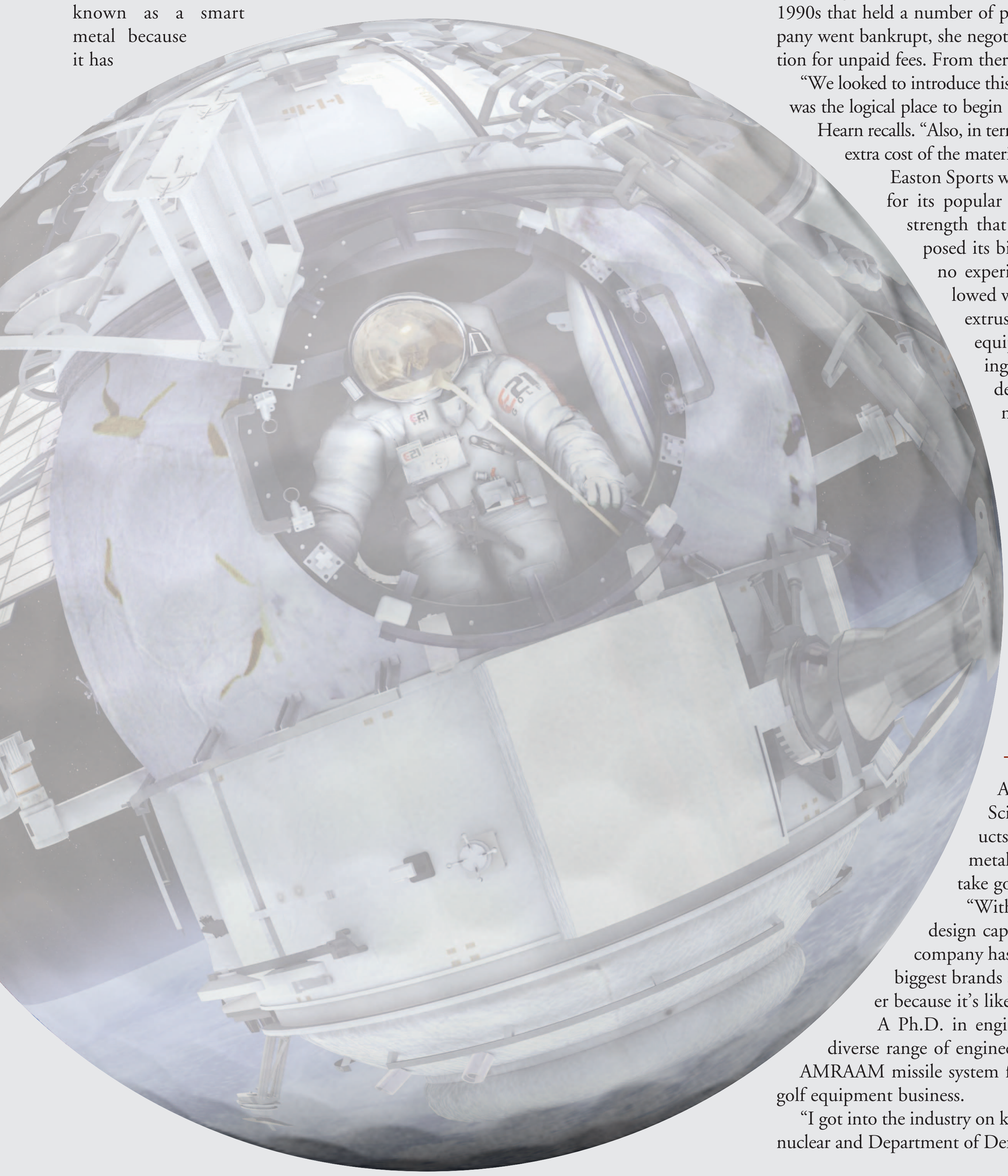
by Mike McLeod

This summer, Pavel Vinogradov will hit a six iron shot farther than any golfer in history. He does have a bit of an unfair advantage though. From a platform affixed to the International Space Station, the Russian cosmonaut will drive a gold-plated golf ball into a low Earth orbit to commemorate the 35th anniversary of Alan Shepard Jr.'s historic Apollo 14 shot on the lunar surface. Estimates predict the ball will travel approximately three and a half billion kilometres before burning up in golf's largest hazard four years later.

Billed as "The Golf Shot around the world," the event will also serve as a PR stunt, envisioned by Element 21 Golf Company (E21), to promote the Toronto-based manufacturer's line of golf shafts and driver heads made from scandium, the 21st element on the periodic table.

While E21's marketing strategy has sparked considerable buzz in the international press, it threatens to overshadow the hard engineering and material science involved in the manufacture of this potentially revolutionary golf equipment. Company president and CEO, Nataliya Hearn, Ph.D., P.Eng., says it doesn't take a jump to light speed to make the connection between aerospace and golf considering that scandium metal alloy comprises much of the International Space Station itself.

"Originally, scandium was used as part of the Soviet space and military programs," says Hearn. "It was used on the nose cones of missiles because it was the only 'light' metal strong enough to go through an icecap when launched from a submarine. It's also been used for the last 20 years in MiG jets, which are still considered the most manoeuvrable planes. In Russia, it was actually known as a smart metal because it has the unique property of being able to rebound quickly to original shape after sustaining high G-forces."



She says the alloy's "smart" properties also make it ideal for golf equipment in that it possesses the highest strength-to-weight ratio of any material used for golf clubs. Approximately 55 percent lighter than titanium alloy, scandium's strength to weight ratio is 70 percent better than steel, 50 percent better than graphite/composite and 25 percent better than titanium, the current standard in the $4 billion a year golf equipment industry.

To date, the company has unveiled a line of variable flex golf shafts, two driver heads and a set of irons that, Hearn says, rival anything on the market in terms of comfort, accuracy and distance.

Given the reception of E21's products in industry circles, it would seem that the golf community agrees. Introduced earlier this year, the company's Shock drivers were named the "Best New Clubs" at the 2006 PGA Merchandise Show by writers from Golf Today Magazine. Additionally, E21's Low Gravity Logic irons received Golfing Magazine's prestigious 2006 "Players' Choice Award" for "Most Forgiving Irons". Hearn says upwards of 80 PGA tour professional golfers have either adopted or are actively testing the company's golf shafts.

"Tour pros are very particular," she says. "The only reason they are trying and using our shafts is that there is a significant performance advantage."

Into the great unknown

Dr. Hearn and scandium took a number of doglegs before landing in the golf industry. A former civil engineering professor at the University of Toronto, Hearn also specialized in technology transfer. As part of her work, she consulted with a public company in the mid-1990s that held a number of patents including that for scandium alloy. When that company went bankrupt, she negotiated a deal for the exclusive material patents as compensation for unpaid fees. From there it was a matter of figuring out what do first, Hearn says.

"We looked to introduce this super-strong material into a number of industries but sports was the logical place to begin because everybody is looking for that additional advantage," Hearn recalls. "Also, in terms of the economics, sports is always capable of absorbing the extra cost of the material because of the mark-ups for high-end products."

Easton Sports was the first western company to license E21's alloy in 1997 for its popular Redline baseball and softball bats. But the exceptional strength that makes scandium so attractive in sports equipment also posed its biggest challenge. In addition, Western manufacturers had no experience working with the material, Hearn says. What followed was two years of pain staking trial and error to create a new extrusion process. From there, the company moved on to golf equipment, but the more sophisticated process of manufacturing golf shafts added another three years to the product's development time. And while baseball had been open to the new material, the golf industry wasn't as receptive.

"We started off as a technology company and never looked to become a golf company," says Hearn, whose vertically-integrated company controls each step in the manufacturing process from design to manufacture to marketing, unlike any other golf equipment company.

"We knew from our experience with Eastern and from our own analysis that scandium was going to be superior to anything available in golf, but the big companies would say 'Show us' at every step of the way," she adds. "So, for instance, they would ask us to bring them 1,000 units to test for consistency. When you have that many units, you might as well start selling them yourself and make a profit."

The physics of golf

According to Dr. J. Howard Butler, president of Golf Science Consultants, says there's more to E21 Golf's products than just the introduction of a new material. It's the metal's unique properties that allow engineers like himself to take golf equipment design to levels previously unattainable.

"With the advent of scandium alloy, we have quite an array of design capabilities that we've never had before," says Butler, whose company has performed design consultation for many of the industry's biggest brands as well as E21. "That makes me pretty excited as a designer because it's like a whole new box of tools to play with."

A Ph.D. in engineering science and mechanics, Butler participated in a diverse range of engineering projects, from the design of nuclear reactors to the AMRAAM missile system for the U.S. Department of Defence, before entering the golf equipment business.

"I got into the industry on kind of a lark and figured it would be a science similar to the nuclear and Department of Defence stuff," recalls Butler who formerly served as vice-president of shaft technology at True Temper Sports, Inc. "It turned out there was very little science involved in golf at that time. It was kind of scary because there were a lot of claims being made that were not necessarily substantiated through proper engineering analysis."

In response, Butler created Shaft Lab, a device that measured the structural loads and impact stresses sustained by golf shafts during the downswing and on contact with the ball. To truly appreciate the significance of scandium alloy, Butler says, you first have to understand the physics of shaft design.

"Most people have a total misconception of what the shaft does," Butler says. "The shaft is strictly there to position the head immediately prior to impact. During impact, the shaft doesn't do anything. For instance, a lot of people believe that if they have a more torsionally stiff shaft that it will help hold the head straight during impact. That's wrong. You could have a piece of spaghetti or a telephone poll for a shaft and they would both have almost exactly the same effect on ball flight during the 500 micro seconds of impact."

During the downswing, however, Butler says many things can happen that affect the club's ultimate performance. One is how well the shaft brings the club head to the optimal position before ball contact. Another is what's known as the kick, or the increased velocity imparted to the club head by a more flexible golf shaft material or design.

"Once you understand the shaft's true role, the goal is to design a product that will respond well during the downswing for an individual," Butler says. "For instance, the higher a golfer's acceleration during the downswing—not the faster but the higher the acceleration—the more load he will apply to the shaft. Typically those people need stiffer products."

In contrast, he adds that, although professional golfers generate relatively high club head speed, if their swing velocity is smooth and even, they don't create the peaks in their acceleration that require a stiffer shaft.

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"My point is that everyone without exception should be fitted with the appropriate amount of flex based on their acceleration or the downswing load they put on the shaft," Butler recommends. "We have changed shafts out for many touring pros who thought they had to use a very stiff product because they were extremely good players. Ironically, it turns out that, the better the player is, the softer shaft he can get away with and play with more effectively. It's backwards from the way the industry thinks."

Enter scandium

To add to the complexity, Butler says that designing "whipiness" or stiffness into a shaft is more nuanced than simply its overall flexibility; it's a matter of where the shaft bends during the downswing.

"We call that the mode shape," he explains. "The first mode shape is important because that is what people feel when they swing. If the shaft is very tip flexible like a fishing rod, they can feel that. So it is important to be able to change the flex or stiffness of the shaft per unit length of the shaft. Not just overall stiffness but whether it is stiff in the tip, middle or butt."

This is where the unique properties of E21's scandium alloy come into play. For example, unlike graphite, Hearn says scandium is an isotropic, homogeneous material (i.e. it has the same properties in all directions). The major benefit, she says, is that every shaft is identical. Added to this, the alloy's high strength to weight ratio, combined with the company's 25-step extrusion process, allows for the shaft to be centreless ground.

"What that means is, they actually take a grinder and change the thickness of the shaft which enables them to change the flexibility of the shaft per unit length," Butler says. "We can't do that with any other isotropic, homogeneous material."

Possibly the most significant benefit of E21's shafts, Hearn says, is that they reduce shock attenuation by 270% over steel shafts—a quality the company calls "ShockBlok". She says the reduced vibration not only produces the crystal clear contact signature of a perfectly hit shot, but it also eliminates the pain every golfer knows of miss-hitting an iron.

"One of the things Davis Love really likes is the feel because it's just not painful to play," Hearn says. "And guys like Chris DiMarco are switching because they all have tendonitis issues from hitting balls for so long."

Off the tee

Beyond shafts, Butler says scandium alloy allowed him to push the design envelope of E21's Shock Driver head as well. In fact, he says the metal allowed his company to attain optimized designs that had formerly been purely theoretical.

Instead of the lengthy process of real-world trial and error, Butler uses a set of proprietary virtualization programs to emulate the performance of design tweaks. The first is an equivalent mass system into which a digital reproduction of a driver prototype's functional properties are programmed. The model is then run through the company's Enhanced Performance Integration Code (EPIC), a program that optimizes the driver's design for maximum performance.

"Then, we look at those requirements the computer says we need and we determined if we have the material and manufacturing ability to build it," says Butler. "Before, we were only able to come reasonably close. With scandium, we can hit it dead on."

One of the main factors that determine driver accuracy, Hearn says, is what's called the bulge and roll of a club face. The face of an iron, for instance, is flat since it's forged from one solid piece of metal. On the other hand, drivers—particularly the oversized variety—are hollow. The driver's face, therefore, has to be slightly convex, or curved outward left to right and up and down, so it won't crush under the force of ball impact.

"Think of an arched bridge," Hearn explains. "You can make it a low arch or a high arch depending on the material you're using or the thickness of that material. With scandium, we can make a flatter arch."

As a result, Hearn says E21's Shock Driver possesses the largest "sweet spot" of any driver on the market and also the highest coefficient of restitution (COR) allowable under the PGA's recently imposed design limits. COR is a measurement of the "trampoline effect" when two bodies, like a club face and golf ball, collide and rebound.

"We knew about the PGA's rule before we designed this club and we built the driver right on the limit," Butler adds. "The computer code indicated that the way the bulges and rolls are set up on the face, along with the inertias and the centre of gravity, we should get minimum dispersions on off centre hits."

While the golfers may not be interested in the engineering specifics, they won't ignore how that translates into shot accuracy. Based on robotic testing, the average dispersion rate—meaning the distance balls land from a centre line on identical 300 yard drives—of E21's Shock driver measured a record-setting 7 yards compared to the 22 yards of leading titanium drivers.

"We're not saying that it is going to hit the ball farther, although some of the tests have shown that," says Butler, who's presently working on scandium enhanced irons he says may rival E21's existing products. "We're saying that if you hit the ball on the club face you should be OK because the driver will bring off-hit shots back to where they are supposed to be."

While the company claims a scientifically superior product, Hearn says E21's business strategy going forward isn't to compete directly with the large golf manufacturers. Instead, she foresees licensing the material not only to the likes of Calloway and Taylor Made but to other kinds of industries far from the terrestrial enterprise of sports equipment.

"Really, the sky is the limit," she says. "Usually you use a new metal in the aerospace or defence industry and then it trickles down to the sports industry. With scandium, because it was a Soviet development, we are using it in sports and then moving into other applications such as aerospace." de