

1 of 120 DOCUMENTS

Aerospace America

March, 2006

Nanotubes lift hopes for **space elevator**

BYLINE: Ben Iannotta, Contributing writer

SECTION: FEATURES; Pg. 30

LENGTH: 2613 words

HIGHLIGHT: Using a nanotube material 100 times stronger than steel and one-sixth the weight, an ultrathin ribbon stretching 62,000 mi. into **space** would let satellites "climb" into orbit. This revolutionary concept, if it comes to fruition, could have profound geopolitical and environmental effects. For example, it would enable the construction of vast arrays of solar panels, which would provide a continuing source of energy, lessening, or even ending, the world's reliance on oil.

Reaching **space** without flying is an idea that has been around since the 19th century. In recent years, the concept has reemerged in the form of the **space elevator**, a proposed 62,000-mi.-long ribbon that would stretch into **space** from a floating platform in the equatorial Pacific Ocean. Satellites or other payloads would be loaded onto unmanned cargo canisters called climbers, which would ascend the paper-thin ribbon by squeezing it between sets of electrically driven rollers. Huge communications satellites or other payloads would be deployed from these climbers to geosynchronous orbit 22,500 mi. above Earth.

Over the last seven years, Bradley Edwards, formerly of Los Alamos National Laboratory, has been credited with giving the most rigorous thought to the components and technical breakthroughs that would be needed to build a **space elevator** in the relatively near future. For each component, Edwards has identified existing technologies or research efforts that could open the door to the required hardware.

By far the greatest challenge would be construction of the 62,000-mi. ribbon. It would need to be made of a new composite material based on superstrong microscopic carbon nanotubes that researchers are attempting to apply to a variety of problems.

Nanotubes are cylindrical carbon molecules identified in 1991 by Japanese scientist Sumio Iijima. In their raw form, they appear as a dark powder similar to graphite. Materials experts at several U.S. universities and Los Alamos are researching nanotubes for use in high-strength materials and nanocircuitry. Edwards hopes to channel private investments into existing nanotube projects to help devise a material 100 times stronger than steel and one-sixth as heavy. If nothing else, advocates are betting that future commercial applications, from golf clubs to running shoes, will fuel the research.

Counting on a revolution

Even advocates admit the **space elevator** will not get off the ground without a new material boasting a revolutionary strength-to-weight ratio. "The material is the question. Therefore the status of the **space elevator** is very much dependent on the ribbon material," says aerospace engineer Pete Swan, who will soon publish a book with Edwards on the proposed system architecture of the **elevator**. Swan and other advocates are encouraged by initial

laboratory work on high-strength nanotube materials.

"The ribbon is moving from science to engineering," says Swan. "We're depending on the commercial world to develop carbon nanotubes, and that's a very believable thing. General Motors will have carbon nanotubes in their design process. Boeing will love carbon nanotubes for composite wings. Nike will love composite materials for their running shoes," he declares.

Making the pieces fall into place

Compared to the ribbon, development of the climbers and other components should be relatively straightforward, because existing engineering approaches can be tapped. Consider the climbers, Edwards says. "You could think of printing presses with paper running through them at high speeds through rollers."

More challenging will be delivering power to the climbers as they ascend the ribbon. Batteries could never store enough electricity to keep them rolling up the ribbon, so Edwards wants to beam laser light to light-sensitive cells on the climbers. For that purpose, he is eyeing a disk-type solid-state laser that Boeing is researching for the Pentagon. The laser light would be projected onto gallium arsenide receivers that would convert the light into voltage.

If his strategy of spinoff breakthroughs succeeds, the **space elevator** would hold numerous advantages over rocket launches, Edwards believes. "You can lift more payload," up to 15 tons on one climber, "and it doesn't need to be as rugged, because there are no vibrations on the **space elevator**," he says. "It costs you 1% as much to launch as it did with rockets. All of a sudden [satellite deployment] becomes economical very quickly.

"Say you have a several hundred million dollar telecommunications satellite that goes on the fritz. You go grab it [carry it down the **elevator**] and put it back out there, instead of spending several hundred million dollars more to put up a new one," he continues.

Beyond higher profit margins, whoever develops the **elevator** will seize the reins of profound geopolitical and environmental changes, Edwards predicts. Suddenly, it would be economically and physically feasible to erect vast solar arrays in **space** to collect sunlight and beam the energy back to Earth. So much energy, in fact, that "Man would be completely independent of oil," he says. "The only thing that you might not be able to convert directly to electricity would be aircraft, because of the high energy densities. But you could convert those to hydrogen," says Edwards.

From "thought exercise" to passion

In 1998, while designing spacecraft components at Los Alamos, Edwards started researching the **elevator** on the side, as a fun "thought exercise." He recalls surfing the Internet and seeing a prediction that a **space elevator** would be built in "300 years to never." Edwards soon found himself brainstorming exactly how a **space elevator** might be built, and in 2000 he left Los Alamos to pursue the concept full time. In 2003 he published a book, *The Space Elevator*, to make his case for the project to the government research community and the aerospace industry. The follow-up book he and Swan are writing will look more specifically at the architecture in hopes of wooing investors.

So far, officials at NASA and Los Alamos have responded by embracing the **elevator's** potential, albeit with thousands rather than millions of dollars. In March 2005, NASA announced it would provide \$ 400,000 in prize money for a **space elevator** technology competition to be run annually by the nonprofit Spaceward Foundation of Mountain View, Calif. The group plans to draw universities and companies to a series of annual competitions pitting experimental components against each other. The prize funding was the first to be allocated under NASA's new Centennial Challenges program, which was formed as the agency's answer to the privately funded X-Prize Competition.

Swan defends the approach of developing and testing the climbers and power systems before the ribbon material is proven.

"You want to have all those things answered to the first level and maybe to the second level before you go to the investor and say, 'I'd like \$ 6 billion or \$ 10 billion,'" he says. "I don't think all the development of carriers and ribbon climbers is premature," he insists.

That is not to say Edwards is not trying to push the state of the ribbon material. In April 2005, Los Alamos announced a research agreement with Carbon Designs (CDI), a company formed in 2004 by Edwards and investment specialist Brent Waller of Dallas. The excitement proved to be short lived when CDI folded, taking a promised \$ 2-million investment with it. "The investors had promised lots of funding and then got a little flaky on us," Edwards says. He is in the process of lining up new investors for a company that will resume the research with Los Alamos under the name X-Tech Projects of Seattle.

An unpredictable result

If the material can be developed, the **elevator's** ribbon would stretch between an orbiting counterweight on one end and the floating platform on the other. The ribbon would have to be nearly three times as long as the distance to geosynchronous orbit to keep the size of the counterweight manageably small. The two-layered ribbon would need to be strong yet paper thin so that it would fit rolled up inside the two rockets that will deploy it. To put it simply, no existing material could do the job.

Even advocates admit that breakthroughs have been hard to come by in the 14 years that nanotubes have been known to scientists. Edwards attributes the slow progress to a scarcity of research dollars rather than to a shortage of raw nanotubes or to fundamental doubts about their potential.

"You can go and buy carbon nanotubes right off the Internet at a number of places," Edwards says. He notes that they are only "\$ 130 a kilogram, which is really pretty inexpensive for what they do." When imaged by a powerful microscope, their uniquely strong molecular structure becomes apparent, he says.

The carbon atoms in nanotubes are arranged in hexagonal molecules, but an important feature distinguishes them from carbon molecules in existing graphite composites. "A graphite sheet is that same hexagonal arrangement of carbon atoms, except it's laid out flat. In that case, you always have edges in a sheet, and that's where the weakness is in the graphite. For the carbon nanotubes, they've rolled those sheets up into tubes, and now we can make endless tubes with no edges," says Edwards.

"It is the strongest arrangement of atoms that you can make with anything, because the carbon-atom bonds are so strong. Not only is it the strongest material we know of, it's the strongest material we'll ever be able to make. They're basically crystal tubes," he notes.

In Edwards' vision, the tubes would be mixed into a polymer to form fibers or threads, which would be woven together and then laid up in epoxy. The process is similar in some respects to the manufacture of traditional graphite composites. One difference, he says, is that the carbon in graphite composites is made by burning polymers to create carbon molecules. In the case of nanotube materials, the tubes are manufactured separately, then added to a polymer.

Studies show that a composite material made of carbon nanotubes should be 60 times as strong as a graphite composite, says Edwards. "That's theoretically," he quickly adds.

He is relying largely on materials expert Yuntian Theodore "Ted" Zhu of Los Alamos to make that theory a reality. Zhu cautions that turning nanotubes into long ribbons of high-strength material will not be simple. Edwards has set a goal of 100 GPa for the amount of force the ribbon must be able to stand without tearing apart. By comparison, the figure for steel is typically about 1 GPa, and less than that for most other building materials, Zhu says.

The longer the carbon nanotube molecules, the stronger the fiber or yarn that can be spun from them, Zhu says. In September 2004, Zhu and scientists from the University of California and Duke University reported creating a

record-setting 4-cm-long nanotube using a process called catalytic chemical vapor deposition from ethanol vapor.

Scientists will almost surely make even longer nanotubes, but for purposes of the **space elevator**, 4 cm "will be enough," Zhu says. "The challenge is how to produce these long nanotubes in large quantity for spinning into large fibers," he adds.

Beyond that, Zhu needs to find a polymer that will adhere adequately to the nanotubes. It is the polymer that must transfer the weight of the climbers to the nanotube molecules to take advantage of their molecular strength. The nanotubes are slick, notes Zhu, and grasping them is "like grabbing a very slippery rope or something," he says. "That's very tricky. How do you transfer loads? We're still in the early stages. We're busy working with various polymers."

Zhu also must find a way to get the tubes to line up correctly inside the polymer. Other scientists have experimented with using electric or magnetic fields to align them, but Zhu says this technique is not practical for large-scale manufacturing, because not enough tubes can be lined up at once.

Zhu is cautious when asked to assess the potential for building a 62,000-mi. ribbon out of nanotubes. "I think we have a good idea. We're making good progress. But it's hard to predict the result," he says.

Deploying the ribbon

The Edwards concept calls for launching two 20-ton rolls of ribbon, each 62,000 mi. long, on separate launch vehicles to geosynchronous orbit. The two ribbons eventually would be pressed together by the first climber to form a single, two-layer ribbon, but first they must be deployed to their full length.

To accomplish that, two additional rockets would boost the halves of a deployment satellite. These halves would join up to form one spacecraft that would autonomously unroll the two ribbons downward toward Earth. The deployment satellite then would use an electric propulsion system to fly to its final orbit 62,000 mi. from Earth, unrolling the remainder of the ribbons along the way. For the propulsion job, Edwards is encouraged by a powerful magneto-plasdynamic thruster currently under study at Princeton University in New Jersey.

With the ribbon unrolled, the deployment satellite would retain a critical role as a counterweight. The centrifugal force from its mass and velocity would offset the tug of gravity on the ribbons to keep them taut.

Back on Earth, the first climber would start its ascent from the floating platform, squeezing the two ribbons together so they become one, with the aid of thin pieces of tape on the facing sides of the ribbons, Edwards explains.

This initial **space elevator** would be reinforced by adding layers of ribbon from the ground up using additional climbers.

A 1,000-ton ribbon with a 500-ton counterweight could support a 5-ton climber carrying 15 tons of payload, calculates Ben Shelef, a mechanical engineer at the component design company Gizmonics in Mountain View, Calif. Gizmonics is supporting Edwards' **space elevator** concept as its "corporate hobby," according to the company Web site.

Shelef says there could be changes from Edwards' concept as more is learned. "The point of the design is that no one is a design nazi. It's very early. We all have ideas," he says.

Vulnerabilities

Edwards and Shelef spend a lot of time answering questions about the potential vulnerabilities of their **elevators** to lightning and saboteurs.

Edwards says the platform will float in the calm equatorial region between the northern and southern hemispheres.

There is almost no chance of lightning damaging the ribbon and no chance of hurricanes harming it, he says.

Both men say strategies would be employed to mitigate some threats, just in case. "When we have the anchor on a boat, we can move around. So that's part of the answer," says Shelef. High-altitude balloons positioned nearby could carry lightning rods, he adds. Edwards says the part of the ribbon near the ground could be made of a nonconductive material. "It would be a lot thicker and heavier, but it would be fine," he adds.

The more serious threat would be saboteurs or military foes. If the ribbon were severed, part would fall to the ground and part would fly off into **space** attached to the counterweight satellite. Partly because of that, Edwards and Shelef are careful not to advocate sending up humans on the **elevator**, at least initially.

As for the falling ribbon, it could short out electrical systems or block highways if it landed in a populated area rather than the ocean, Edwards says. But, he adds, its light weight would make it unlikely to harm anyone by landing on them. "It would feel like a heavy blanket."

The real threat, he says, is that someone other than the U.S. will build the **elevator** first.

"The U.S. government is not that forward thinking. They're sort of half putting their heads in the sand, thinking, 'Aw, we're the only ones who do **space**.' At some point, they could be rudely awakened -- the Chinese are one of the leaders in carbon nanotubes," notes Edwards.

LOAD-DATE: March 14, 2006

LANGUAGE: ENGLISH

GRAPHIC: Picture 1, Laser light would be beamed to light-sensitive cells on the climbers. The light would be projected onto GaAs receivers that would convert the light into voltage., Copyright © 2006 by the American Institute of Aeronautics and Astronautics.; Picture 2, Payloads would be loaded onto unmanned cargo canisters, which would ascend the paper-thin ribbon by squeezing it between sets of electrically driven rollers.; Pictures 3 through 6, Los Alamos scientists grew a 4-cm-long carbon nanotube molecule -- one like those that might someday form the **space elevator's** ribbon -- on a slice of blank silicon substrate. The scientists used a dip pen to apply an iron-chloride catalyst to one end of the silicon strand, placed the substrate inside a furnace, and exposed the catalyst end to hot ethanol vapor. This generated a chemical reaction that deposited carbon atoms along the length of the substrate. Portions of the finished tube are seen in b, c, and d. It would be impossible to show the complete tube in one image -- the diameter is so small that the tube would be invisible.; Picture 7, The destinations for the **space elevator** may be limited only by our imagination.