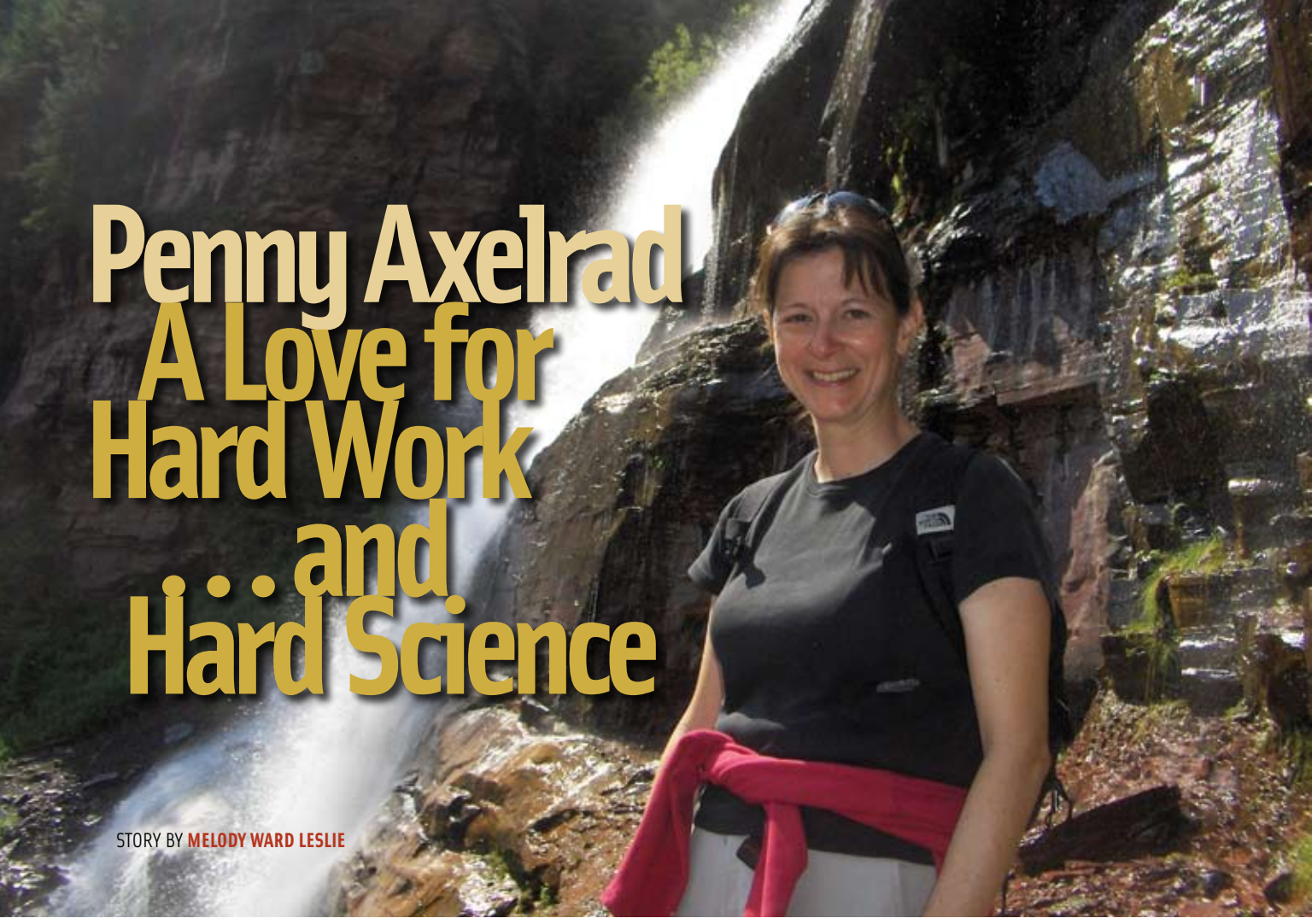

Penny Axelrad A Love for Hard Work and Hard Science

STORY BY **MELODY WARD LESLIE**

One of ace aerospace engineering professor Penny Axelrad's favorite stories about her early days in GPS research involves a Fiat and an inspired sign featuring the radioactive symbol.

She and fellow Stanford graduate student Kevin Fitzgibbon were getting nasty looks from honking motorists as they crept along a back road in his late-model Fiat, conducting dynamic tests on algorithms for positioning using early-model, 19-inch rack-mount Trimble surveying equipment.

After enduring about an hour of flack from drivers who had taken that road in order to indulge their need for speed, the pair hit on the idea of making a sign for the back windshield: *Caution — Radio wave experiments in progress.*

"Given the proximity to the Stanford Linear Accelerator, this must have seemed a dangerous enough proposition, because people backed off," Axelrad says.

Today Axelrad is a well-known professor of aerospace engineering sciences with the Colorado Center for Astrodynamics Research (CCAR) at the University of Colorado in Boulder.

She is a Fellow of the Institute of Navigation (ION) and the American Institute of Aeronautics and Astronautics (AIAA), and a senior member of the Institute of Electrical and Electronics Engineers. Her many contributions to GPS have garnered laurels including the 1996 Lawrence Sperry Award from the AIAA and the 2003 Tycho Brahe award from the ION.

Growing up in the New York City borough of Queens, Axelrad always liked math and science. "The harder it became, the more I liked it," she says, adding that her father, a chemistry professor, has been a life-long inspiration.

Her exceptional promise as a GPS innovator first surfaced during her co-op program at MIT (also known as the "fire hose of opportunity.") There she completed her bachelor's and master's degrees in aeronautical and astronautical engineering in 1986 while working on the Space Station Alpha project as an intern at Hughes Aircraft in Los Angeles.

When she arrived at Hughes, they were talking about using GPS for positioning the space station. Landsat had just flown the first non-classified spaceborne receiver, and Axelrad's master's thesis evaluated how accurately the space station orbit could be determined by using GPS pseudorange observations. It was her introduction to Kalman filters (see "Favorite Equation" in Compass Points) and a practical application of satellite dynamics.

Finding a Cure for the GPS Blues

After finishing up her master's thesis, Axelrad was, in her own words, "pretty sick of GPS." So, in the spring of 1986 she set off for Stanford University with the goal of studying interplanetary trajectories with Professor John Breakwell.

HUMAN ENGINEERING

At Stanford, however, a cure for her GPS malaise came in the form of an offer she couldn't refuse: a research associate position with Brad Parkinson, then the Edward C. Wells Professor of Aeronautics & Astronautics and program manager for NASA's Gravity Probe-B Program. Her "penultimate mentor," Parkinson was the first director of the GPS Joint Program Office and one of the fathers of the GPS field.

"That was a terrific opportunity," Axelrad says. "It changed me and it changed the course of my life."

Parkinson had all kinds of ideas about things to look at with GPS, and Axelrad couldn't resist the challenge of undertaking a thesis on applying GPS to onboard orbit determination for Gravity Probe B — NASA's long-standing effort to measure two effects predicted by Einstein's theory of general relativity by means of a spacecraft flight. Along the way, she was involved in early developments of a technique for ensuring GNSS integrity known as RAIM, (receiver autonomous integrity monitoring).

"I've been working in GPS ever since," she says. "I keep learning new things related to it. Along the way I've had to learn about signal processing, remote sensing, antennas — things I wouldn't have pursued absent GPS."

After completing her Ph.D. in aeronautics and astronautics at Stanford in 1991, Axelrad went to work for Stanford Telecommunications in Santa Clara, California, to gain experience building GPS receivers.

"It's one thing to use receivers," she says. But building them was something else again. "I really learned a lot, and I had terrific mentors there as well."

While working at the pioneer GPS company, Axelrad also taught two courses at Stanford University, an experience that sealed her lifelong aspiration to become a professor.

Teaching & Research in the Rockies

In 1992, she joined the aerospace engineering faculty at the University of Colorado (CU) where she has pursued a wide variety of GPS-related research projects including spacecraft attitude determination and remote sensing with GPS bistatic radar.

Bistatic refers to a radar system in which the transmitter is located at a site different from the receiver — which happens to be the basic configuration of the Global

COMPASS POINTS

Engineering Specialties
Applications of GPS for aircraft, spacecraft, and remote sensing. She focuses mainly on the algorithms but has also dabbled in some hardware and software over the years.

Her Compass Points
- Family — husband and children, parents, and sister
- The University of Colorado — great colleagues, especially Kristine Larson, Dennis Akos, and Scott Palo, outstanding students, wonderful opportunities
- Research and teaching
- Boulder, Colorado — the best possible place to live

Favorite Equation
The Kalman Filter Gain Equation distributes how you use a new measurement in adjusting your state estimate based on a balance between how well you already know the answer, how accurate the measurement is, and the geometrical relationship between the measurement and the states to be estimated.

K = P H' (H P H' + R) ^-1

First Fell In Love With GNSS
1986, as a co-op student from MIT working in the system engineering group of the Hughes Space and Communications Division.

Knew GNSS Had Arrived When . . .
"Two winters ago, I was sitting on a chairlift with two 10-year-olds and the kids were comparing notes on whose dad had a cooler GPS system in his car."

First Significant GNSS Achievement
Investigated the application of GPS to onboard orbit determination for Gravity Probe B for autonomous orbit insertion. (Her approach was not used operationally, but it was interesting.)

Engineering Mentors
Richard Battin, John Kelly, Brad Parkinson, Quyen Hua, Bob Rennard, George Born.

Influences of Engineering Outside Work
"Engineering has a tremendous impact on how I think, not only in my research, but also in my teaching and in how I interact with people. The study of engineering teaches you to think clearly. You learn how to break down complex problems into digestible pieces, to sanity-check your answers, to think of several ways to approach things. It helps me be able to sort things out and understand things in life in general. I think it gives you confidence that you can figure things out."

Popular Notion About GNSS That Most Annoys
"The suspicion that the U.S. will turn off or disrupt GPS to cause trouble for other countries."

Favorite Non-GNSS Activities
Spending time with her family — especially skiing.

What's Next
Understanding the fundamental impacts of the Internet on how students — and people in general — learn, think, and innovate.

Positioning System with its transmitters on orbiting satellites 12,000 miles in space and receivers spread around the globe.

"Normally when people want to study surfaces, they will shoot a radar signal at it and measure a reflection," she says. "The advantage of using GPS in this configuration is you don't have to send a signal out, because the earth is bathed in these signals. You just have to set up an instrument to receive them."

By deliberately tracking signals reflected by objects in the environment, Axelrad and her students are gathering useful information about the different types of surfaces on the earth. Their work is leading to applications ranging from measuring the moisture content of soils to categorizing sea ice to measuring an aircraft's height above terrain.

"In practice," she cautions, "there's still a lot of work to be done to make these techniques robust and reliable, but it is an exciting and sort of unintended use of GPS."

At CCAR, Axelrad's teaching contributions include the development of a graduate laboratory course in GPS technology and an undergraduate lab course on aerospace electronics and communications. She helped lead a major undergraduate curriculum revision within the aerospace engineering department to improve student experience through increased hands-on learning.

Above all, Axelrad enjoys working alongside her graduate students, whom she views as colleagues.

"You learn a lot from them and they pull you into new areas because they each have their own interests," she says. "I feel such pride and pleasure when they graduate and move on to take great positions at places like JPL, GSFC, Purdue, Ball Aerospace, DigitalGlobe, Boeing."

Axelrad's professional activities have led to her inclusion among 12 contemporary women in a variety of aerospace careers featured in the Sally Ride pamphlet series, *Totally Amazing Careers in Science*. The pamphlets are designed to inspire girls to enter the so-called STEM fields: science, technology, engineering, and mathematics.

Let Us Now Praise Hard Work
Busy as she is with research, her students, and service to her profession, Axelrad has also contributed to the development of a middle-school curriculum on navigation. It's part of the extensive amount of time she devotes to efforts aimed at strengthening math and science education from kindergarten through high school.

But Axelrad takes a rather tough-love approach to her pedagogy. She warns that students who become addicted to encouragement that is not based on actual accomplishment "don't develop the tenacity to deal with setbacks and push through a rough patch" to find an answer.

"Unfortunately, many kids and adults think that something hard is to be avoided," she says. So, the next step is crucial: helping them learn how to work hard and to be

Axelrad with family at Telluride: husband Tim Perley and children, Aaron and Rachel

persistent and creative in problem-solving. "Students must understand how to learn from mistakes and criticism, and then legitimately feel the light bulb pop when they gain new insights," Axelrad says.

And, for parents of daughters, a special word of advice.

"In middle school you need to make sure they stay with it, because that's typically when girls go from being good in math and science to basically bailing out."

In fact, Axelrad has been forming a theory about why

Axelrad's coordinates:
N 40 0.42 W 105 15.7 H 1630 meters

fewer girls enter science and engineering professions.

"It struck me that just as many boys as girls tell their parents and counselors they are not interested, but we all expect that our sons will have to support themselves," she says. "So, we don't hesitate to tell boys that the top-paying undergraduate jobs are in chemical, aerospace, and electrical engineering, and that they should stick with it."

" I think people are more likely to be accepting of girls' statements. — We don't want to be discouraging; so, maybe we are less likely to challenge these statements from our daughters and nieces and neighbors. Maybe what we should be saying is, 'You know, you really are good at it, I think you should stick with it." IG

Human Engineering is a regular feature that highlights some of the personalities behind the technologies, products, and programs of the GNSS community. We welcome readers' recommendations of candidates for future profiles. Contact Glen Gibbons, <glen@insidegnss.com>.