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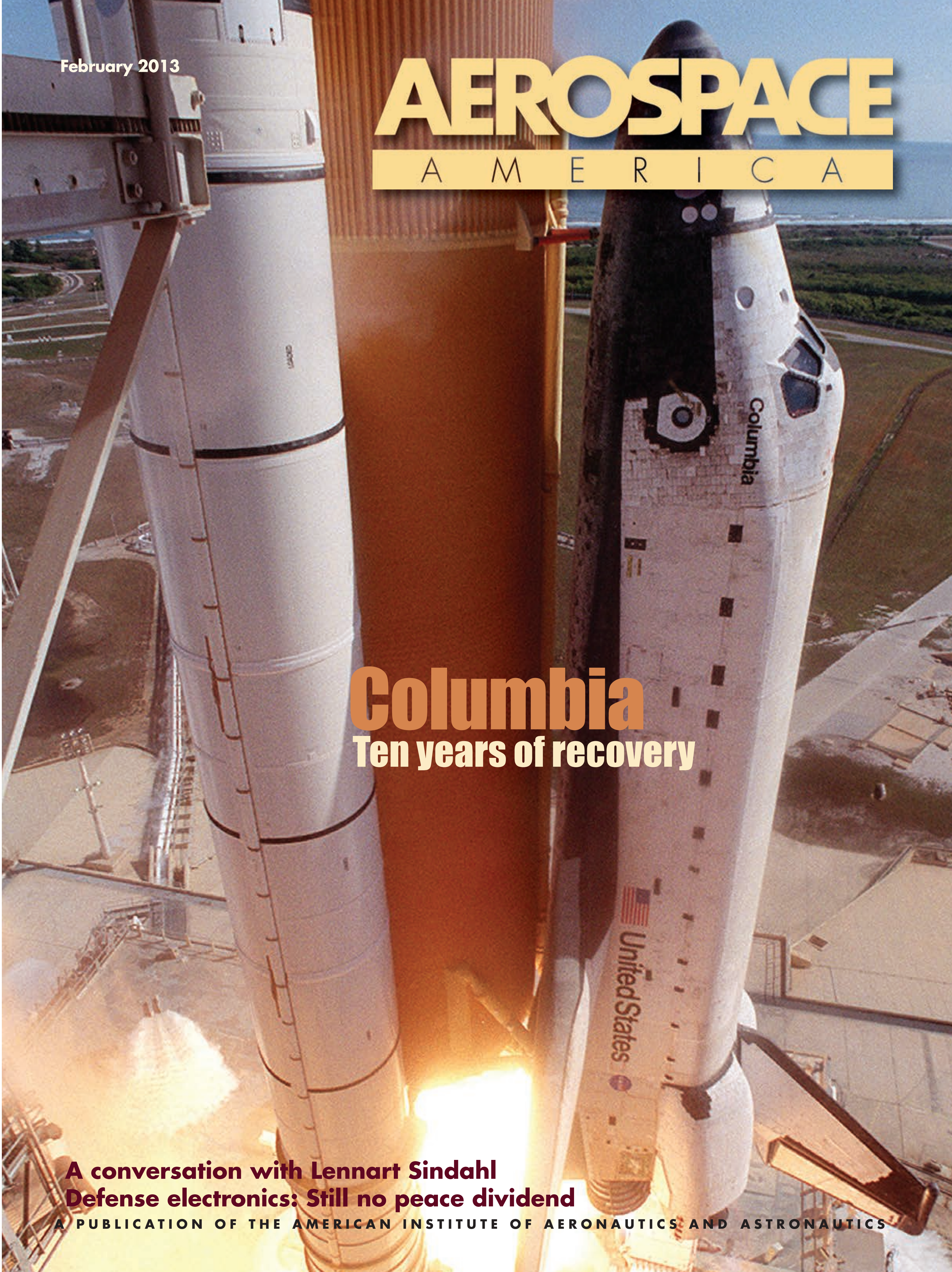

## Columbia
### Ten years of recovery

**A conversation with Lennart Sindahl**

**Defense electronics: Still no peace dividend**

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# Communicating with a Dragon

The Dragon capsule’s rendezvous with the space station in May showed that computer analysis and modeling have found increasing acceptance in NASA and industry for verifying communications on even the most delicate missions.

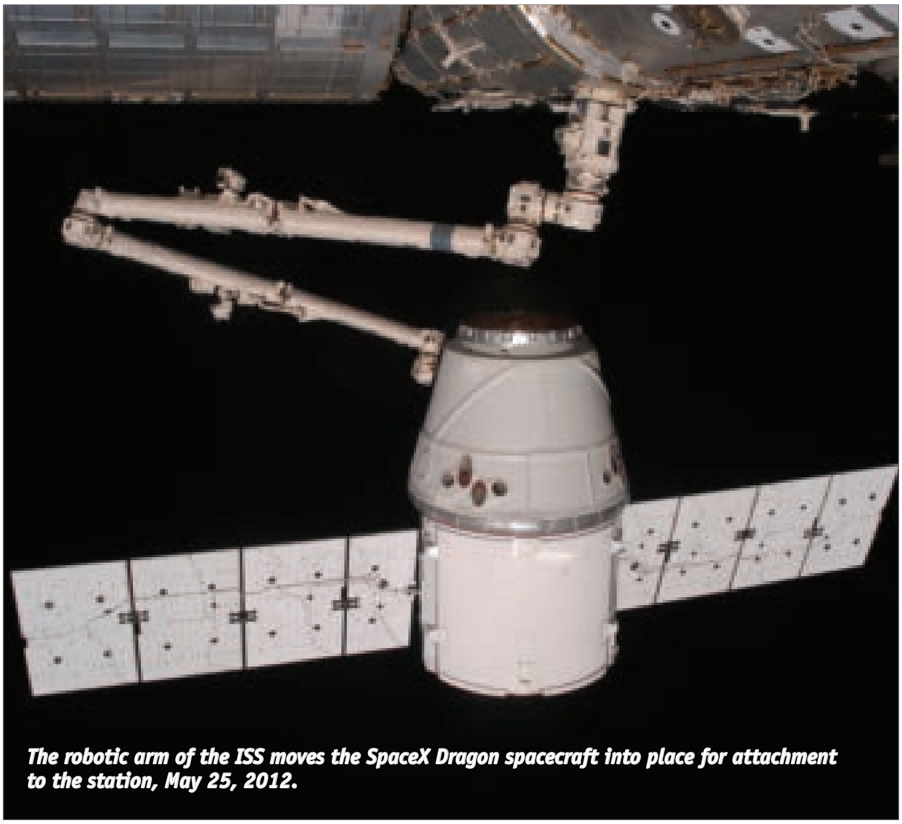
The 6,000-kg Dragon capsule featured 30 conformal antennas as it closed in on the station. The antennas kept Dragon in contact with mission controllers either directly, when the craft was in range, or indirectly via orbiting Tracking and Data Relay Satellites (TDRS). Other antennas provided GPS coordinates and linked the Dragon to the ISS during a confidence-building flyby beneath the station and, shortly after that, during the rendezvous itself.

During development, Dragon’s designer and builder, SpaceX, relied entirely on subsystem hardware tests, computer modeling, and analysis to gain confidence in the complex communications system.

“I would prefer to put the whole vehicle in an anechoic chamber if I were going to be really conservative,” acknowledges Steve Pollmann, manager of SpaceX’s radio frequency (RF) work. “But in this case we didn’t have a chamber big enough,” he says.

NASA was responsible for the safety of the mission and was satisfied with the preparations even without a chamber test.

“There were quite a bit of tests done along the way,” says systems engineer Mike Horkachuck, project executive for NASA’s work with SpaceX. There were “RF checkouts of the basic antenna as a piece part; and then after it was installed in the vehicle there were more RF checks. So it wasn’t done completely by analysis,” he says. As for full-up tests, Dragon communicated before launch via TDRS through the atmosphere, Horkachuck says.



***The robotic arm of the ISS moves the SpaceX Dragon spacecraft into place for attachment to the station, May 25, 2012.***

## ‘Next level’

The antennas for Dragon and its Falcon 9 carrier rocket were built by Haigh-Farr of Bedford, N.H., as a vendor to SpaceX. Haigh-Farr has made antennas for other space missions, including the Mars Science Lab now studying the red planet, but Dragon was different because of the human element.

“This was definitely taking it to the next level,” says CEO David Farr, whose father, George, founded the company in 1968 with Bill Haigh. Last year, Vitec Group purchased the company, making it a business unit.

In addition to building Dragon’s antennas, Haigh-Farr was responsible for accurately modeling the antenna RF patterns for SpaceX, which needed them for larger system-level analyses.

The big challenge for Haigh-Farr was to depict digitally how the radiation emitted by one antenna would interact with the surface of the capsule and with signals from other antennas.

Haigh-Farr engineers applied powerful computers and CAD tools. They developed finite-element models of Dragon and Falcon 9 so that the structures’ physical characteristics—such as electromagnetism—could be represented in each cell of the models.

“What we have done is increase our computer capability to get these very large objects, such as a whole Falcon 9 or Dragon capsule, in the computer in a finite-element model, so that we can calculate these patterns,” Farr explains.

There would be no anechoic chamber test of the entire vehicle.

Haigh-Farr’s reliance on computer analysis is not an approach that arose from nowhere. It was the culmination of 20 years of investment in computing innovations, modeling, and anechoic chamber tests on flight articles for other missions, Farr says.

## Avoiding outages

Farr does not recommend taking shortcuts when it comes to understanding antenna patterns.

"We have seen in the past, especially in a lot of satellite applications, that companies have not considered the radiation characteristics [that are] actually on their satellite or on their vehicle," Farr says. "They've taken the basic characteristics of their antenna when mounted on an ideal ground plane and assumed that's what it's going to be when they use it. That's not necessarily the case."

A lot can go wrong. Consider a conformal, omnidirectional antenna—Haigh-Farr's are made of a glass-impregnated teflon/ceramic material. Imagine it is wrapped around a cylindrical spacecraft. The antenna's energy does not only radiate into space.

"You will launch surface currents around the outside of the cylinder," Farr says. "So now you have another source, another amplitude and phase off both ends, plus the main amplitude and phase from the antenna itself," he explains.

Engineers must know exactly how the signals from that antenna and spacecraft surface will interact. If the phases are 180 deg apart from each other, they could cancel or null each other. "If you are looking from your receiving site or transmission site to the spacecraft, and you have a null right there, you're going to lose contact," says Farr.

The challenges are even bigger when complex shapes are considered, such as Dragon or the missiles for which Haigh-Farr also designs antennas. "You can imagine that if you add a wing or a fin or some other protrusion, you can wind up with energy scattering from the well," he cautions. Engineers need to establish the radiating characteristics, and plug that into software that conducts a full, dynamic link analysis under various conditions. This is what SpaceX did for Dragon.

Matters were complicated when all the different bands and temperature ranges were taken into account. On Dragon, S Band was used for telemetry and video. There were also C band transponders and antennas for GPS positioning. Dragon needed both omnidirectional antennas and directional antennas for communications via the TDRSs.

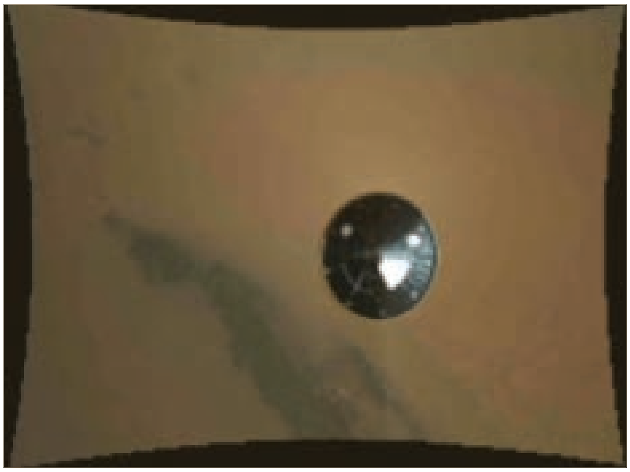
On Dragon, or any mission, engineers must be confident the antennas will keep working through the required range of temperatures. Heating or cooling of a material can impact the amplitude and frequency of the signals. "If the resident frequency was shifting because we were down very cold or up very high in temperature, then you could wind up with a serious mismatch, a transmission loss," explains Farr.

Engineers needed to make sure this would not happen during the Dragon mission. "You may lose signal due to this, and of course, the antennas that we're doing for Falcon 9 and a lot of other launch vehicles are for flight termination. So that's critical," Farr says.

## Confidence builder

Dragon was not Haigh-Farr's first space foray. NASA's Phoenix Lander communicated through eight Haigh-Farr conformal antennas during its landing on Mars in May 2008. The Mars Science Lab (MSL) used a similar antenna system to close in on the red planet in August.

Farr says that because of the company's history of modeling, he was confident of the antenna performance as he monitored the Dragon mission on Spaceflight Now and exchanged emails with SpaceX engineers.


*The MSL used antennas from Haigh-Farr as it approached Mars.*

Providing a big boost was a series of ground tests on the antennas aboard the Mars Science Lab. The tests were described in the undated paper, "Radiation Pattern Measurements of the NASA Mars Science Laboratory UHF Entry Antenna Using a Spherical Near-field Range." Farr and two coauthors wrote it to explain how the MSL team assessed antenna performance without placing the entire spacecraft in a chamber.

As with Dragon, that was not considered feasible because of the spacecraft's size. The team elected to conduct chamber tests on a fifth-scale model of the entire assembly, plus separate chamber tests on the actual flight nosecone. Those tests took place at Nearfield System in Torrance, California, in the company's spherical near-field test facility, which is lined with 1-m-thick, pyramid-shaped, anechoic absorbing material.

The team made radiation pattern measurements before and after application of the thermal protection system materials. That was important, because the choice of such materials can affect the reliability of communications signals.

"It's important that we know the characteristics of the material at elevated temperatures," Farr explains. "There are some materials out there that will char, for example…some of them char into carbon, and carbon can be a very bad thing to have over an antenna. It can prevent you from radiating."

Because the antenna must transmit through the thermal protective material, engineers must choose one with electrical parameters that are as consistent as possible over a range of temperatures. "If you have a material that radically changes, that can perturb the radiation characteristics of the antenna. And if it changes enough it could actually degrade them to the point where it's an issue," Farr says.

On MSL, the team compared their computer model predictions to the patterns measured before and after application of the thermal protection materials. "Good agreement between the patterns indicated that the fifth-scale-model measurements and the calculated patterns on the entire entry vehicle were valid," they concluded.

Both the subscale tests and nose-cone tests gave the MSL engineers enough confidence to rely on modeling in assessing the antenna performance for the entire lander system.

### Off-the-shelf tools

For Haigh-Farr, the breakthrough in digital analysis started about 12 years ago. The company's engineers were developing their own code for analyzing structures, but they realized there was a burgeoning industry dedicated to developing 3D modeling tools. So they decided to tap into it.

"There were a couple of companies out there that were really taking this to a new level," Farr says. "We were able to interface with AutoCAD and other solid models that make importation of these kinds of structures a lot simpler."

The resulting 3D computer models turned out to be game changers.

"Before, you had to describe [a structure] in a numerical fashion. It wasn't an object you could look at on the screen; you would have to look at a series of numbers," Farr says.

The transition to commercial 3D tools freed the company's engineers to work on bigger problems—namely, how to scale up the modeling and RF pattern analysis technique to larger objects.

"I like to say what we have pioneered—or worked on very diligently—is becoming very good at using these tools to calculate the [radio frequency] pattern," Farr explains. "We also developed the computer horsepower necessary to take [a] whole object and create a finite-element model, because it takes a tremendous amount of memory," Farr adds.

### The cost savings challenge

Although known for its cost-cutting derring-do, SpaceX did not use that approach with the first two Dragon vehicles, which had more antennas and radios than the company, ultimately, would like.

"Our main objective was to meet all the safety and contractual agreements we have with NASA in order to do the cargo delivery," says Pollmann of SpaceX. "Cost was definitely a factor in, say, some of our component choices, but the main objective wasn't necessarily cost savings."

SpaceX is beginning to look at how it can reduce the cost of future capsules, however. "We're looking at seeing if we can reduce the number of antennas and the number of radios," Pollmann says. They want to do this while maintaining "two-fault tolerance," which means that if two radios failed, controllers could still communicate with the capsule.

"We've got to look at it and be a little bit more intelligent on how we design the next version of the comms system," Pollmann explains. "We don't have to be as conservative, because we have actual data from the missions we've flown."

In other words, Dragon's success will mean new challenges for antenna designers like Haigh-Farr. Mission engineers throughout the industry are demanding higher bandwidth, multiple channels, and the ability to withstand even greater extremes of temperature, shock, and vibration, particularly for missile applications, Farr says.

Trustworthy modeling will be more important than ever. **Ben Iannotta**
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