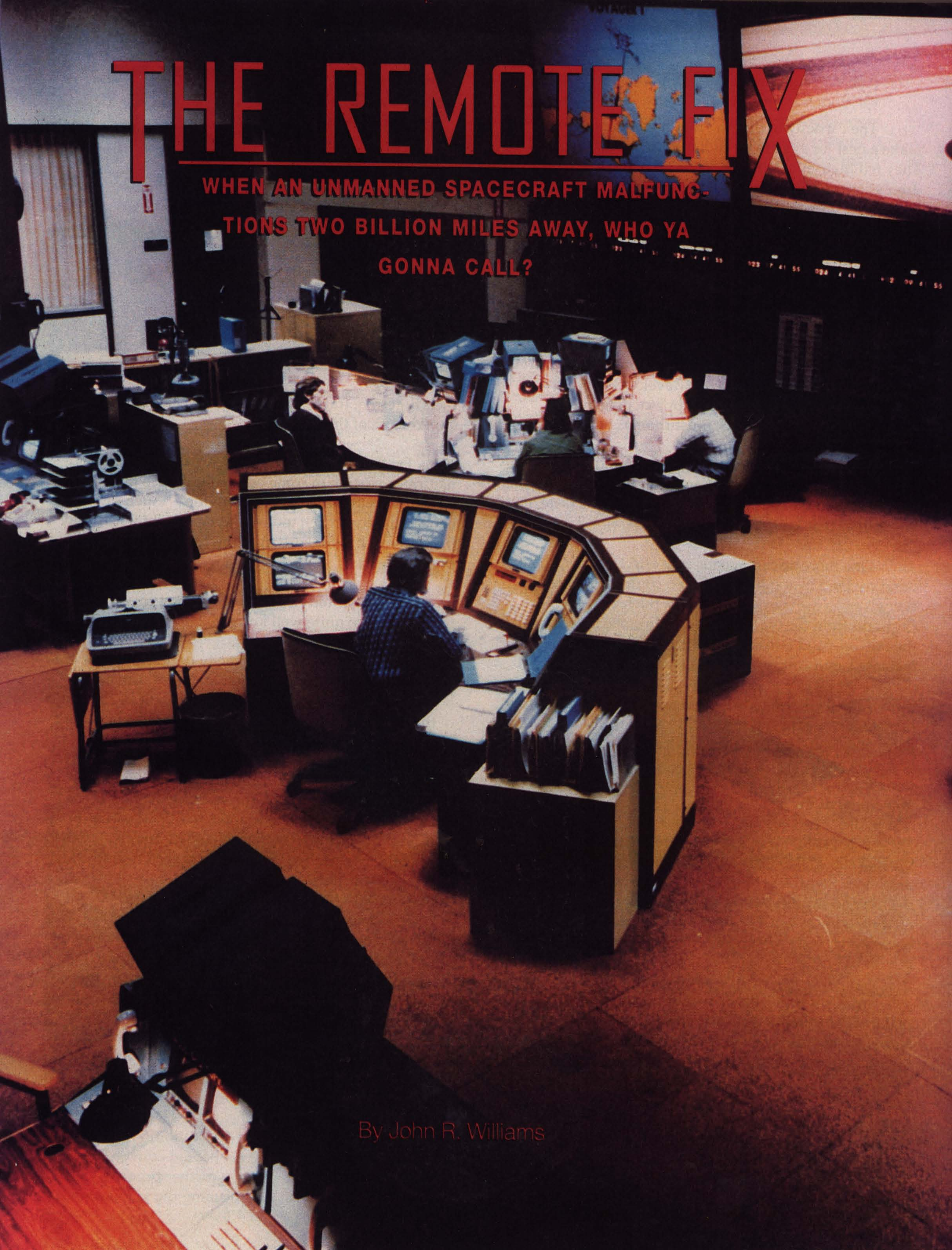

THE REMOTE FIX

WHEN AN UNMANNED SPACECRAFT MALFUNCTIONS TWO BILLION MILES AWAY, WHO YA GONNA CALL?

By John R. Williams

For Gary Coyle, watching Galileo's main antenna unfurl was supposed to be the high point of his involvement with the mission. Coyle, the senior technical engineer for Galileo's main antenna, and the rest of the engineers, scientists and journalists at the Jet Propulsion Laboratory watched in anticipation for the umbrella-like antenna to open. Although the event was not particularly important compared to a planetary flyby, it was a significant chapter in Galileo's journey to our Solar System's largest planet, Jupiter. Without the antenna, at least 90 percent of the data gathered by the spacecraft would never reach Earth.

Engineers watched closely as computer screens hummed with incoming flight data to determine whether Galileo's computers executed the planned deployment. Yes, it was opening...no, it stopped. And there it stayed—stowed in a closed position since it was launched by the space shuttle more than ten months earlier. The catastrophe took everyone, including Coyle, by surprise. "The first thing I felt was shock and disappointment," recalls the engineer. "It was the most painful experience of my 30 years watching these craft. But that feeling lasts only a minute in the control room because after that everyone's brain is trying to figure out what the problem is and find a solution." The more complex the equipment, the more likely there are to be problems— that's been the unwritten code among engineers since the invention of the wheel. NASA is no exception. As the space agency's robotic missions to explore the Solar System have become more daring and the instrumentation more sophisticated, NASA engineers have often found themselves playing the role of high-tech troubleshooters. They face a challenge that few other engineers on Earth have encountered: repairing a malfunctioning piece of equipment that may be nearly two billion miles away from the nearest toolbox.

The problems afflicting NASA's robotic fleet vary from the exotic to the mundane. Voyager 1's mission to explore the outer Solar System, for instance, was endangered when a piece of plastic worked its way into the gear assembly that drove the scan platform. The platform moves up and down to point the camera, as well as the infrared and ultraviolet instruments. Engineers solved that problem by running the platform back and forth, grinding down the intruding piece of plastic.

The scan platform onboard Voyager 2 also became stuck, shortly after the space probe encountered Saturn in 1981. To get a better handle on what the spacecraft was experiencing, engineers tested similar parts they had on the ground. They found that lubrication was being forced out of the platform's gears, causing the system to jam. If left alone for a while, the lubrication would seep back into the gears. But if engineers ran it at its top speed of one degree per second, the platform would jam again. They found they could run the platform indefinitely, however, if they ran it at its slow speed of 1/12 degree per second.

Unfortunately, not all mechanical problems can be solved so easily. With Galileo, engineers scratched their heads for weeks, uncertain whether the antenna had actually failed to open or whether it had opened, but was suffering some sort of technical failure.

Finally, there was a breakthrough. A "star sensor," used to navigate the craft, was obscured by one of the antenna's ribs. By carefully analyzing light data from the sensor, engineers could accurately map the position of three of the ribs. By backtracking, they could plot the position of the other ribs and precisely determine the antenna's orientation. It soon became clear that the antenna had, in fact, failed to unfurl.

Armed with this knowledge, the engineers planned a course of action. As Galileo sped away from Earth after its gravity assist in December 1990, JPL instructed the craft to alternately turn the antenna toward the Sun and then away toward the cold of space. This heating and cooling routine, known as thermal cycling, creates expansion and contraction which should cause the ribs to pop, enabling the antenna to open.

Space is an unforgiving environment for a piece of high-tech hardware.

Although the first attempt at thermal cycling was unsuccessful, engineers will try again during Galileo's next Earth assist in January 1993. As the spacecraft moves closer to the Sun, it will warm up. When the antenna approaches room temperature—the temperature at which it was actually assembled—its fittings will slide back into their original configuration. This, Coyle says, will guarantee a better chance of success.

Unfortunately for NASA, mechanical problems—jammed platforms, stuck antennas and the like—are just the tip of the iceberg. Technical failures are the most common problem plaguing the space agency's fleet of robotic explorers. Space is an unforgiving environment for a piece of high-tech hardware. Just as rust eats away at your car, atomic oxygen eats away at spacecraft coverings. High-energy particles degrade solar panels and zap delicate circuitry, while radiation causes computers to slowly lose their minds. Even the most hardy spacecraft could be destroyed by a high-speed crash with an object the size of a pea. Different types of missions pose different types of threats. Magellan, for example, was designed to endure the super-hot temperatures it would encounter during its orbit around Venus. Yet, Magellan wouldn't stand a chance of surviving the intense radiation belts that Galileo will encounter at Jupiter.

To combat the myriad of potentially damaging effects, NASA scientists and engineers use several options. The brute-force option adds metal shielding around delicate and critical electronics to block incoming particles. Physical shielding isn't always enough, however. Some cosmic ray particles pack enough punch to pass through the Earth as if it weren't even there. An aluminum shield 35 inches thick could stop most high-energy particles, but that would leave little room for the electrical components that actually make up the spacecraft.

Scientists can "harden" electronics to withstand the constant bombardment of particles, but only at a price. For example, you can jog down to the local computer store and pick up a one-megabyte chip of memory for about $100. Harden that chip against the environment of space and the price skyrockets to $1 million.

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If any of this shielding isn't enough, engineers can write computer software to patch possible problems. The programs help compensate for technical failures, telling the spacecraft what to do until ground controllers can give specific guidance. Without such precautions and care, scientists could easily end up with a dead spacecraft.

Single Event Upsets, or SEUs, are probably the most serious problem facing today's spacecraft, says Ron Draper, project manager for the upcoming Cassini probe to Saturn. "Data can be lost or a mission can be destroyed if the wrong command is sent to, say, the computer in charge of attitude and articulation," Draper says. Only one of several, this computer keeps solar cells pointed at the Sun for power, antennas pointed at the Earth for communication, and sensors pointed at the stars for navigation. Scientific instruments also communicate with the computer to coordinate the space probe's orientation. A single faulty number in a stream of computer data can cause the spacecraft to point in the wrong direction. At best, a planet or moon under investigation would be missed. In a worst-case scenario, the spacecraft's communication link with Earth would be lost and never again re-established.

So far, out of all of NASA's interplanetary fleet, no two probes have experienced the exact same problem. Coyle credits this to the robust nature of the space agency's craft. The basic design is good, he says, but the individual parts sometimes cause trouble.

Case in point: the Voyager 1 probe in 1978. The main receiver aboard the

(continued on page 52)

Remote Fix

(continued from page 32)

spacecraft failed, and JPL engineers switched over to the backup receiver. Unfortunately, the backup receiver was soon discovered to be tone-deaf. Of the 20,000 to 40,000 hertz bandwidth available for communication, only a 200-hertz-wide frequency remained. This immediately created two problems for technicians at JPL. The first was caused by a phenomenon known as the Doppler Effect. Radio waves transmitted from Earth undergo a change in frequency as they are received by a space probe that is rapidly moving away from our home planet. As a solution, ground stations were given software to counter the Doppler Effect and maintain the proper frequency.

The second problem involved temperature. A change aboard Voyager of just one-quarter of a degree Celsius could push the frequency out of the narrow bandwidth. From that moment on, scientific instruments were ordered into a strict ballet. Careful planning kept that mission healthy. If researchers were not using a particular instrument, it was shut off. When many instruments were in use—especially during the spacecraft's closest encounter with Uranus—the spacecraft became too hot, and all communications were temporarily lost. Voyager was instructed ahead of time to carry out a set of instructions and then shut off all its instruments. In time the craft would cool down, and engineers could re-establish contact.

Magellan is experiencing problems as well. Right after it entered orbit around Venus, contact with the craft was lost. Scientists called it "walkabout" because the signal was lost twice while stations in Australia were tracking the craft, according to Douglas Griffith, Magellan's project manager at JPL. "The bug to this problem was extremely hard to find," Griffith admitted. "Though it took no time to fix once it was found. It was a very subtle problem."

Engineers found that Magellan was not closing one computer command before it went on to the next. This created an infinite loop and basically caused the craft to "daydream." Without input from the computer, the craft's pointing program allowed its antenna to wander away from the Earth and lose contact. Before the problem was finally solved, engineers gave the spacecraft a software patch to help counter the effects of the "walkabout." They sent a program telling Magellan to stop everything it was doing, point its solar cells toward the Sun for energy and its antenna toward the Earth for instructions. Not long after that, engineers fixed the computer glitch, although they are now faced with an even more challenging problem.

This time, it's the transmitter. Although engineers have never been able to pinpoint the exact cause of the failure, they suspect it's a capacitor, a device that is used to regulate voltage. But with them on Earth and Magellan at Venus, it's hard to tell for sure. However, they know enough about it to combat its effects. Through trial and error, engineers found they could optimize the transmitter's performance by raising its temperature to 56 degrees Celsius. The transmitter remained healthy throughout the mapping mission, but once again showed signs of deterioration during the summer of 1992. Scientists shut the transmitter off in mid-July in an effort to extend its operational lifetime. On September 3, they turned the transmitter back on when the probe was in position to map an additional 1.5 percent of the planet. By working around Magellan's problems, engineers exceeded expectations by mapping 97.5 percent of the planet when scientists expected only 70 percent.

Not all engineers' tinkering ends in success, however. Just consider the former Soviet Union's Phobos 1 and Phobos 2 probes to Mars. Engineers forgot to communicate with Phobos 1, and it permanently lost contact with Earth. Phobos 2 teased scientists with one picture of Mars's moons before it also lost contact with Earth. And NASA has had its taste of failure. Although Viking's mission was nearing an end anyway, communication and other equipment failures caused the demise of Lander 1 in 1978.

It seems that no matter what precautions the space agency takes, its robotic explorers will inevitably fall prey to human error and the laws of physics. But when the inevitable occurs, NASA can at least take comfort in the determination of its engineers. JPL, for instance, already has a backup plan in mind just in case the thermal cycling of the Galileo probe fails to open its antenna in 1993. They have determined that the antenna's motors can apply a sufficient amount of twisting force to cause the ribs to pop open, a process known as "hammering."

Coyle says that engineers want to rely on the low-impact method first, but that they're "not afraid" to try hammering. His faith in the durability of Galileo was made evident when, after a moment, he added: "We know the spacecraft can handle it."■

Contributing editor John R. Williams wrote about Topex/Poseidon in our September/October issue.