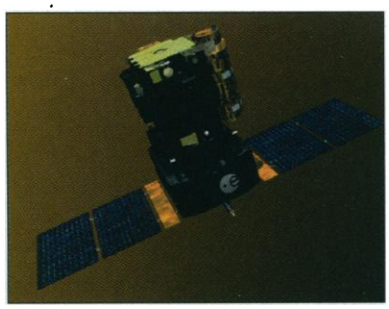
SPACE SCIENCE

Chain of Errors Hurled Probe Into Spin

The loss of the $1 billion Solar and Heliospheric Observatory (SOHO) has exposed a long chain of software and control errors, a NASA review panel has found. The report says a pair of software bugs laid the groundwork for a disastrous command from controllers at NASA's Goddard Space Flight Center in Greenbelt, Maryland, which caused SOHO to spin out of control early on 25 June. *Science* has learned that the debacle also revealed other foul-ups, which played smaller roles in the loss: a third software bug, which may have distracted the flight operations team during the crisis, and the failure of three of SOHO's four emergency batteries.



SOHO

Twisting in the solar wind. The SOHO solar probe, now feared lost.

The panel, which issued its preliminary report last week, is not writing an epitaph for SOHO, which had been watching the sun for two-and-a-half years and was expected to keep gathering data into the next millennium. The spacecraft, a joint project of NASA and the European Space Agency, is now mute and is thought to be tumbling in an orientation that prevents its solar panels from collecting sunlight and generating power. As it moves around the sun over the next few weeks, however, the panels may rotate sunward again and enable the craft to answer NASA's calls. But Joseph Gurman of NASA Goddard, the U.S. project scientist for SOHO, says the debacle holds important lessons. "We ended up with a system that was more complex than was consonant with the very highest degree of safety," he says.

The incident centered on two gyroscopes, called A and B, which sense the spacecraft's roll—its rotation around its longest axis, which is normally aimed at the sun. Because of slight imbalances and electronic inaccuracies in the gyros, they must be calibrated occasionally to determine their "drift," or the amount of actual roll SOHO has when the gyros read zero. To help with the fine-tuning, gyro B's output is set to 20 times its normal sensitivity during calibration. The first software error—introduced during a recent effort to streamline the SOHO software—left gyro B in its hypersensitive mode after calibration rather than resetting it. "It was left indicating roll rates 20 times greater than actual," says Gurman.

This error caused trouble when controllers at Goddard began a second routine procedure, in which SOHO's thrusters are fired to hold the spacecraft steady while a set of wheels, accelerated to twist the spacecraft during maneuvers, are slowed from the high rates of spin they acquire over time. As soon as the procedure was finished, gyro B began telling SOHO, incorrectly, that the spacecraft was spinning 20 times too fast. On the evening of 24 June, the spacecraft went into a mode called Emergency Sun Reacquisition (ESR). Triggered automatically if SOHO detects anomalies in its orientation, ESR fires thrusters to reorient the craft toward the sun.

At that point, a second critical software bug did its damage. To save wear and tear, gyro A shuts off while the wheels are braked. But because a necessary command sequence had been omitted from onboard software during a rewrite about a year ago, gyro A, unknown to controllers, had failed to come back on. Gyro B's erroneous output had, by then, been reset, but it conflicted with gyro A's false zero. And while this problem was developing, other errors cropped up in software written for a recent move to a new control room. Controllers hustled down a hall to the original room, where they hoped the instrument readings would be more reliable.

Here, they took the fateful step described succinctly in the report: "A rapid decision was made that gyro B was faulty and should be commanded off." When gyro A reads zero, SOHO's thrusters fire briefly to compensate for its drift and stabilize the spacecraft. But because gyro A continued to give its false zero, the thrusters had been firing continuously, spinning SOHO faster and faster. Its befuddled sensors triggered two more ESRs, eventually sending it flailing out of control, like a ballerina tripped in midpirouette. Communications faded rapidly as the solar panels lost sunlight—far too rapidly, one panel member says. Surprised controllers now found that undetected failures sometime earlier this year had taken out three of the four batteries.

Michael Greenfield, an official in NASA's Office of Safety and Mission Assurance who co-chaired the panel, puts the blame squarely on the controllers' decision to turn off gyro B. "The team had sufficient time—over 24 hours the spacecraft would have been stable—to reevaluate what to do," he says. "You generally stop, call in experts, senior management. That was not done."

Others, however, point out that many individual failures contributed to the loss. "We've got to avoid any finger-pointing," says Goddard's Art Poland, the previous SOHO project scientist, who emphasizes the scientific successes the mission has already scored. "Each of us can share part of the blame," agrees Gurman, who was on vacation at the time. "If I had been driving the *Titanic*, would it have hit the iceberg?"

–JAMES GLANZ

GLACIOLOGY

West Antarctica's Weak Underbelly Giving Way?

The news out of West Antarctica remains unsettling. Early this month, researchers sifting through mud drilled from beneath the West Antarctic Ice Sheet reported that the massive pile of ice had disintegrated to next to nothing at least once in the past 1.3 million years (*Science*, 3 July, p. 17), presumably during a warm interlude between ice ages. Now, space radar images hint that the ice sheet may be weakening again in today's warming world. One of the glaciers flowing from the ice sheet into the sea—a glacier that has long been seen as the ice sheet's weak point—is eating into stabler ice at a startling rate.

The observations, reported on page 549 of this issue of *Science* by radar scientist Eric Rignot of the Jet Propulsion Laboratory in Pasadena, California, show that the "grounding line" of the Pine Island Glacier—where

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End of the line. The Pine Island Glacier could soon be dumping more of the West Antarctic Ice Sheet into the sea.

ice resting on its bed gives way to floating ice—has been retreating inland at a rate of more than a kilometer per year, presumably because the glacier is losing mass by melting at its base. "That's not catastrophic yet," says glaciologist Richard Alley of Pennsylvania State University in State College, "but most models indicate [that the retreat] would speed up if it kept going."

And that, say some glaciologists, might be a first step toward the collapse of the entire West Antarctic Ice Sheet, which covers