Voyager Bulletin

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Scan Platform Is Healthy

Voyager 2 is expected to return nearly 6,000 images of Uranus and its satellites over a 4-month period in late 1985 and early 1986, but there was a time when the ability of the spacecraft to complete its Uranus mission as planned was in grave doubt due to problems with a scan platform actuator. The actuator controls movement of the steerable platform on which the remote sensing instruments are mounted.

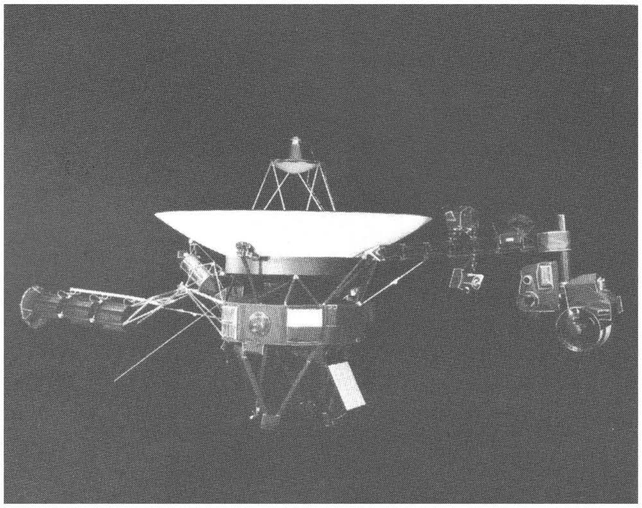
The fact that the scan platform will be used at Uranus is due to an intensive program of detective work to determine the cause of the failure, to devise ways to use the platform in the future, and to monitor its health.

The Onset

On August 25, 1981, Voyager 2 passed within 101,000 kilometers (63,000 miles) of Saturn's cloudtops, the bulk of its Saturn observations completed. Still to come were observations of the planet's dark side and southern hemisphere, the underside of the rings, and several satellites. Right on schedule, radio communications ceased as the spacecraft entered the planet's shadow and the planet's bulk blocked radio signals. During this hour-and-a-half Earth occultation period, the spacecraft was programmed to continue its observations, recording the data for later transmission to Earth. As the spacecraft emerged from behind the planet shortly after midnight on August 26*, communications resumed and it was immediately apparent that the scan platform had trouble. The images showed deep space rather than Saturn's rings. Engineering telemetry showed that the platform had failed to complete a high rate (one degree per second) slew in azimuth (on Earth, this would be the horizontal direction).

Fault protection routines onboard the spacecraft detected the failure and automatically commanded the platform to slew to a "safe" position to protect the delicate optics of the instruments from direct sunlight, but this slew also stopped short. The platform appeared to have seized in the azimuth axis.

At first, it was thought that the problem was similar to that experienced on Voyager 1 in early 1978. In that case, the probable cause of platform sticking was a small piece of debris (possibly plastic) in the gear train. The platform was freed by running the gears back and forth until the debris broke up or was crushed and normal motion was restored.



Voyager's scan platform (far right) carries the wide- and narrow-angle cameras, ultraviolet spectrometer, infrared interferometer/ spectrometer, and photopolarimeter.

Several days after the Saturn flyby, commands were sent to Voyager 2 to perform several small low-rate slews necessary to obtain some critical science observations. These were successful. Normal slewing resumed, and the platform was used sparingly and with no further problems for the remainder of the Saturn encounter period. Two weeks after the failure first occurred, the platform stopped again during engineering tests designed to evaluate slewing behavior and actuator operation at all slew rates. The cause of the failure seemed different from that on Voyager 1.

All slewing was restricted on Voyager 2 while an intensive program of testing was conducted on the ground to determine the cause of the failure, determine the best operating conditions, and estimate the remaining lifetime of a failed actuator once it was restored to operation. In view of the actuator's recovery immediately following the failure, there was some hope that the platform could be used for the Uranus encounter.

Ground Tests

The scan platform on each Voyager is driven by two actuators to point the instruments in azimuth and elevation. Each actuator consists of a permanent magnet stepper motor, reduction gearing, and potentiometers. The entire assembly is about the size of a small coffee can. These elements are sealed within a pressurized aluminum housing filled with nitrogen gas to protect the mechanisms from corrosive gases prior to launch and to preserve the lubricant. The actuators can point the platform with an overall accuracy better than

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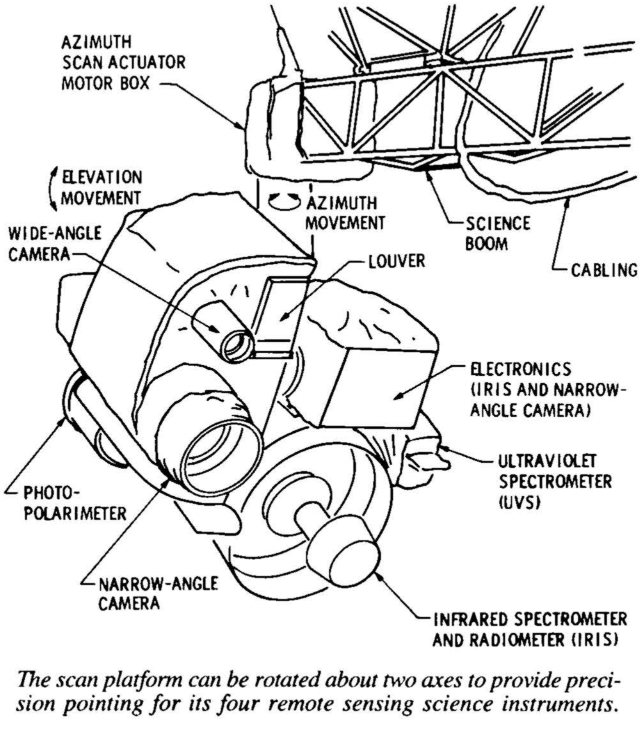
**Times given are Earth-receipt of signal, Pacific Daylight Time. At that time, signals from the spacecraft required about 1 hour 26 minutes to reach Earth, travelling at the speed of light.*

0.14 degree, travelling in steps of 0.028 degree at one of four rates: high (1 degree per second), medium (1/3 degree per second), low (1/12 degree per second) and very low (1/192 degree per second). The azimuth actuator can travel nearly 360 degrees, while the elevation actuator can travel through about 210 degrees.

The ground tests focused on three areas: using the prototype actuator to determine the cause of the failure, trying to recover motion in the flight spare actuator once it was purposely failed, and operating vital mechanical parts under a variety of conditions.

The first tests, conducted by mechanical engineer Carl Marchetto, tried to duplicate the failure, operating a prototype actuator in simulated flight conditions. The prototype failed after 348 revolutions—four less than the actuator on the spacecraft. Both devices had failed much sooner than their designers expected. Upon disassembling and examining the prototype actuator, it was found that the first gear cluster had seized on its supporting shaft, apparently due to a lubrication failure which led to galling of the shaft. Material removed during the galling process was redistributed, eventually reducing clearances between moving parts and ultimately causing the gear cluster to seize.

With a theory of the primary cause of the failure set forth, the next step was to test the flight spare, a unit constructed at the same time as the four actuators on the two spacecraft. This unit was also operated until it failed, but rather than disassemble it (since it was the nearest thing to a flight actuator available, it wouldn't be wise to destroy it), engineers tried various ways to recover (restart) it. The most effective method proved to be varying the actuator's temperature from +10°C to −35°C (50°F to −31°F) [normal operating temperature on the spacecraft is −7°C (19°F)]. The temperature can be controlled by turning on instruments, the actuator heater, and the motor coils in different combinations. The temperature changes cause the actuator's parts to expand at different rates, crushing any material that might accumulate from the galling process.



The scan platform can be rotated about two axes to provide precision pointing for its four remote sensing science instruments.

The flight spare was intentionally failed at various rates and recovered many times under a variety of conditions. Statistics were gathered regarding its probability of failure.

"We found out fairly soon that slew rates were a big factor in the failure. The flight spare never failed at low rate, almost always at high rate, and sometimes at medium rate," said Bill McLaughlin, manager of Voyager's Flight Engineering Office.

The third series of ground tests investigated operating conditions that might affect the actuator's lifetime. Numerous "boxes" of bearing/gear assemblies were built by JPL's specialty machine shop and lubricated for these tests. (A very few were tested without lubrication and failed immediately.) The boxes were run at various rates until they failed, then motion was restored by varying the temperature. After failure and recovery, groups of boxes were then subjected to different operating conditions. Their operating lifetimes after failure and recovery were statistically compared using a test developed by Donna Wolff of the Flight Engineering Office. In this way, optimal operating conditions were developed for future use of the flight actuator.

"Experts also chemically analyzed the interaction between the lubricant and the shaft materials, and used an electron microscope to analyze the bearing surfaces," explained Mike Socha, a mechanical engineer in JPL's Guidance and Control Section.

This phase of testing provided the information necessary to develop the failure model and to recommend how to use the actuator. The tests showed that actuator life is significantly lengthened by low rate operation and an additional temperature cycle.

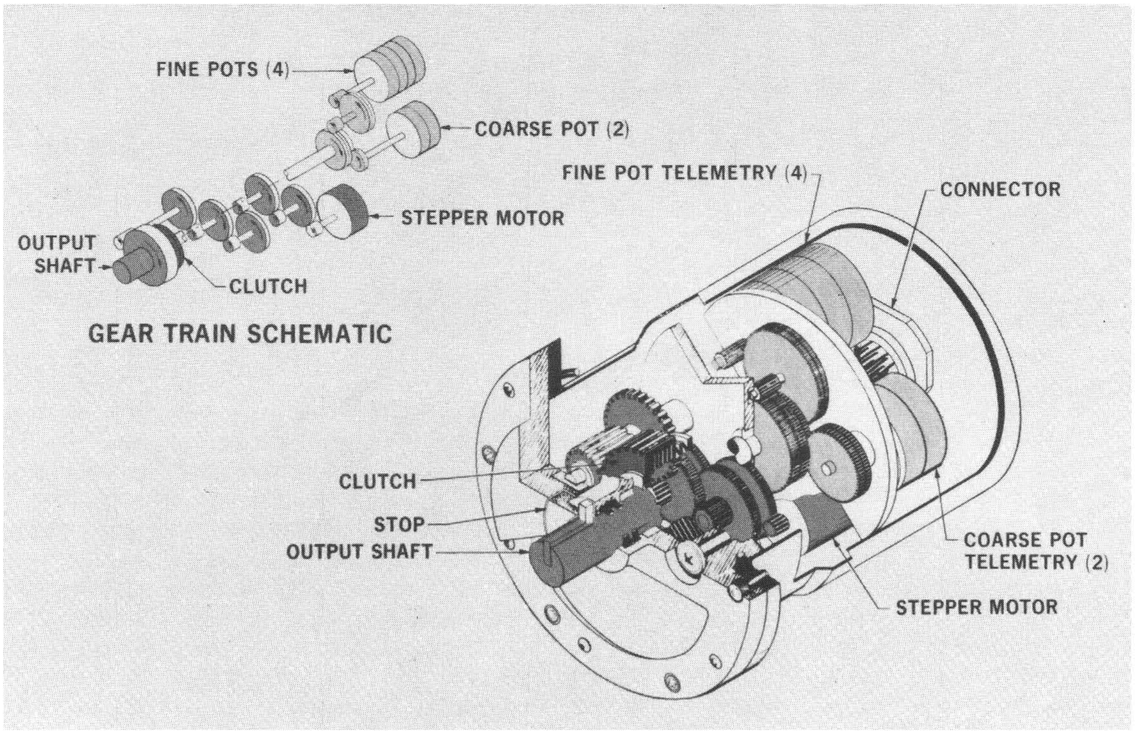
"Through this series of tests we gained a lot of information on how to keep an actuator going and what to do should the flight actuator seize again," said McLaughlin.

Health Checks

"There was a desperate need for a way to assess the health of the in-flight actuators," explained Howard Marderness, chief of Voyager's Spacecraft Team. "In late 1982, we began to develop ways to evaluate the torque margin of the in-flight actuators. One possibility involved varying the power-on pulse width to the drive stepper motor."

Reducing the pulse width reduces the torque applied by the motor to the gear train. If the pulse width is reduced enough, even a perfectly healthy actuator will fail to slew properly due to frictional losses in the system. The normal pulse width applied is 120 ms when slewing at the low rate.

"At first there appeared to be no way of varying the pulse width in the required range," said Marderness. After about four months of study, however, Gene Hanover and Jitendra Mehta of the guidance and control area conceived a means of doing this. Design and ground testing of the torque margin test patch was completed in mid-1983 and was first tested on the Voyager 1 actuators in August 1983. This was followed by testing of the Voyager 2 actuators in



The actuator problem is attributed to a lack of full lubrication in the bearing areas. Lubrication appears to have migrated back, healing the problem.

September 1983. The test results were very encouraging in that all four actuators onboard the two Voyager spacecraft slewed normally at pulse widths between 5 and 6 ms, which, as determined from ground tests, is about the same as for a new actuator. If erratic slewing behavior is noted at 8 ms, for example, it would be a good indication that the actuator was beginning to fail again. Currently, the actuators are monitored by periodic torque margin tests.

Critical Test Before Uranus

About 100 hours before closest approach to Uranus, a critical torque margin test will take place. Should the test show that the actuator's performance has degraded, a backup encounter program will be sent to the spacecraft. This program will involve rolling the entire spacecraft to point the instruments.

The spacecraft roll axis and the scan platform's azimuth axis are nearly parallel, so roll motion of the entire spacecraft, together with motion of the scan platform in elevation, can be used to point the scan platform's instruments if necessary.*

The use of roll turns would allow basic observations at Uranus, but is not as desirable as pointing the platform. Scan platform pointing is generally more accurate, "settling time" is longer after a roll turn than after a platform slew, and commanded spacecraft turns require more computer instructions than does a slew command. There is also more risk involved in turning the spacecraft and more propellant is used.

Summary

No problems have returned on Voyager 2's azimuth actuator since operations resumed over two years ago. However, the actuator is being monitored periodically and used conservatively.

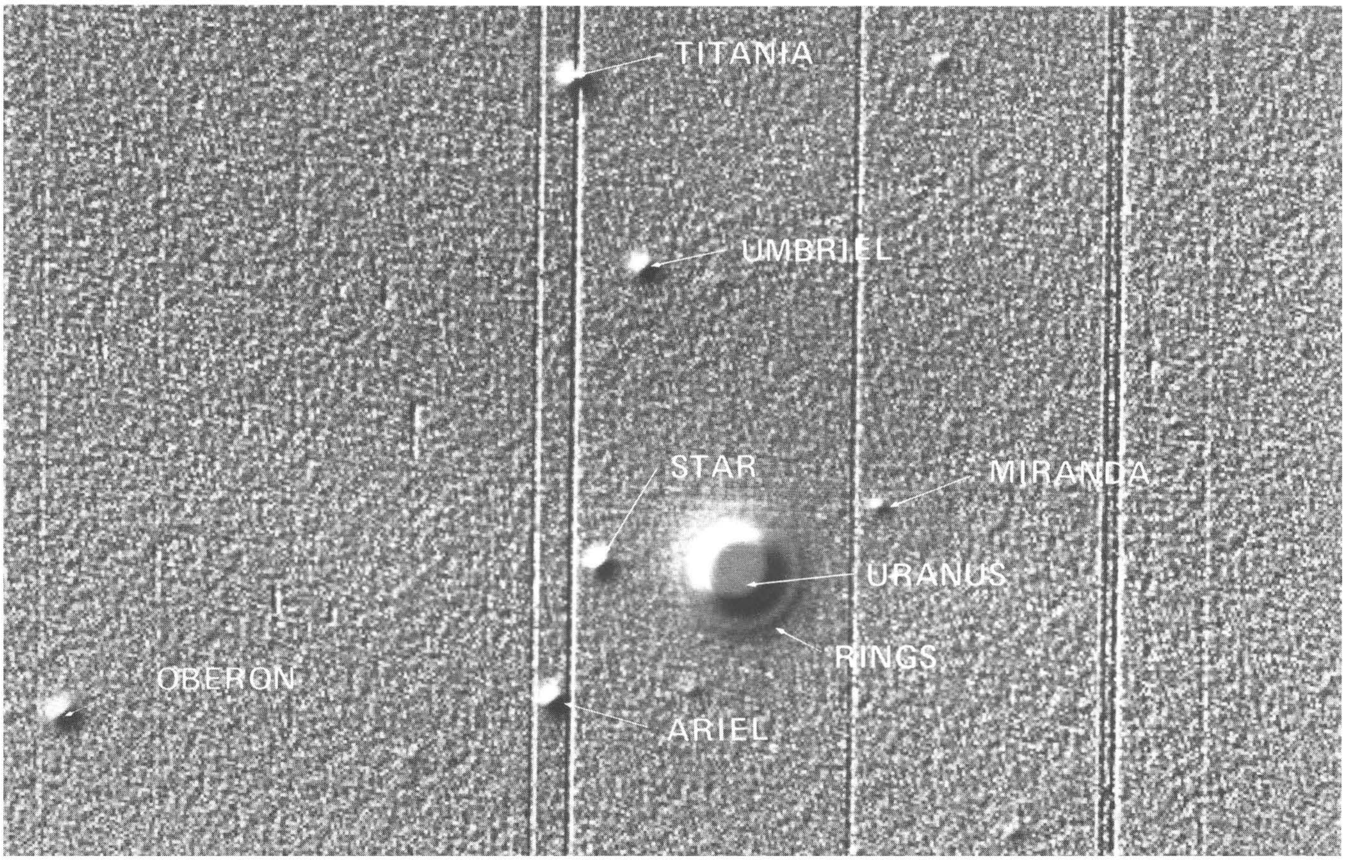
The final report on ground testing of the actuator attributes the failure to a lack of full lubrication of the bearing area between the gear and pin. Frictional heat builds up and causes the lubricant to become less viscous, leave the bearing area, and allow metal to metal contact. A complex chain of chemical reactions between the lubricants and materials also contributes to the manufacture of debris which then interferes with free motion.

It is speculated that the lubricant has migrated back to the bearing surfaces, thus healing the problem.

At Uranus, the platform slews will be primarily at low rate with a small number of medium rate slews for critical science observations. Eight roll turns have been substituted for large angle slews where possible. If there are any indications of problems just prior to the intensive encounter phase, a computer program will be sent to the spacecraft to substitute spacecraft roll turns for azimuth slews.

"Platform slewing is no longer a major topic for us," said McLaughlin. "We've developed plans to cope with it, and we've gone on to develop other capabilities and to train our staff to assure a successful Uranus encounter."

**If the spacecraft's elevation actuator were to seize, it would be difficult to substitute spacecraft turns for scan platform motion as both pitch and yaw turns point the high gain antenna away from Earth, thus breaking the communications link. Data would have to be recorded for later transmission to Earth.*



The first clear photograph of the rings of the planet Uranus is shown in this image taken from Earth. Computer processing creates a false three-dimensional texture to the image, but allows the dark rings to be seen near the much brighter planet. The collective ring system is shown, as the nine individual rings could not be resolved. The photo was taken by a new electronic camera employing a charge-coupled device (CCD) to record the original image. Bright vertical lines on the image are caused by minor defects in the detector. Dr. Richard J. Terrile of the Jet Propulsion Laboratory and Dr. Bradford A. Smith of the University of Arizona took the image at the Carnegie Institution's Las Campañas Observatory near La Serena, Chile.

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