

American Association for the Advancement of Science

Science serves its readers as a forum for the presentation and discussion of important issues related to the advancement of science, including the presentation of minority or conflicting points of view, rather than by publishing only material on which a consensus has been reached. Accordingly, all articles published in *Science*—including editorials, news and comment, and book reviews—are signed and reflect the individual views of the authors and not official points of view adopted by the AAAS or the institutions with which the authors are affiliated.

Publisher: Richard S. Nicholson

Editor: Daniel E. Koshland, Jr.

News Editor: Ellis Rubinstein

Managing Editor: Patricia A. Morgan

Deputy Editors: Philip H. Abelson (*Engineering and Applied Sciences*); John I. Brauman (*Physical Sciences*)

EDITORIAL STAFF

Assistant Managing Editor: Monica M. Bradford

Senior Editor: Eleanor Butz

Associate Editors: Keith W. Broekelhurst, Martha Coleman, R. Brooks Hanson, Barbara Jansy, Katrina L. Kerner, Edith Meyers, Linda J. Miller, Phillip D. Szuroni, David F. Voss

Letters Editor: Christine Gilbert

Book Reviews: Katherine Livingston, *editor*; Susan Millius

Contributing Editor: Lawrence I. Grossman

Chief Production Editor: Ellen E. Murphy

Editing Department: Lois Schmitt, *head*; Mary McDaniel, Patricia L. Moe, Barbara P. Ordway

Copy Desk: Joi S. Granger, Jane Hurd, MaryBeth Shartle, Beverly Shields

Production Manager: James Landry

Assistant Production Manager: Kathleen C. Fishback

Art Director: Yolanda M. Rook

Graphics and Production: Holly Bishop, Julie Cherry, Catherine S. Siskos

Systems Analyst: William Carter

NEWS STAFF

Correspondent-at-Large: Barbara J. Culliton

Deputy News Editors: Roger Lewin, Colin Norman

News and Comment/Research News: Mark H. Crawford, Constance Holden, Richard A. Kerr, Eliot Marshall, Jean L. Marx, Joseph Palca, Robert Pool, Leslie Roberts, Marjorie Sun, M. Mitchell Waldrop

European Correspondent: Jeremy Cherfas

West Coast Correspondent: Marcia Barinaga

BUSINESS STAFF

Circulation Director: John G. Colson

Fulfillment Manager: Ann Ragland

Business Staff Manager: Deborah Rivera-Wienhold

Classified Advertising Supervisor: Karen Morgenstern

ADVERTISING REPRESENTATIVES

Director: Earl J. Scherago

Traffic Manager: Donna Rivera

Traffic Manager (Recruitment): Gwen Canter

Advertising Sales Manager: Richard L. Charles

Marketing Manager: Herbert L. Burkland

Employment Sales Manager: Edward C. Keller

Sales: New York, NY 10036; J. Kevin Henebry, 1515 Broadway (212-730-1050); Scotch Plains, NJ 07076; C. Richard Callis, 12 Unami Lane (201-889-4873); Chicago, IL 60914; Jack Ryan, 525 W. Higgins Rd. (312-885-8675); San Jose, CA 95112; Bob Brindley, 310 S. 16th St. (408-998-4690); Dorset, VT 05251; Fred W. Dieffenbach, Kent Hill Rd. (802-867-5581); Damascus, MD 20872; Rick Sommer, 11318 Kings Valley Dr. (301-972-9270); U.K., Europe: Nick Jones, +44(0647)52918; Telex 42513; FAX (0647) 52053.

Information for contributors appears on page Xi of the 30 June 1989 issue. Editorial correspondence, including requests for permission to reprint and reprint orders, should be sent to 1333 H Street, NW, Washington, DC 20005. Telephone: 202-326-6500. **Advertising correspondence** should be sent to Tenth Floor, 1515 Broadway, New York, NY 10036. Telephone 212-730-1050 or WU Telex 968082 SCHERAGO, or FAX 212-382-3725.

The Human-Voyager 2 Collaboration

The successful Grand Tour of the outer planets by Voyager 2 represents one of humanity's great achievements. The splendid outcome* of the mission carried out in forbidding and hostile environments was due to exemplary exercise of imagination, ingenuity, careful design, and a high level of human-machine operational interaction. An essential ingredient was excellent engineering capability at the Jet Propulsion Laboratory (JPL) that had been nurtured by earlier Mariner missions to the inner planets. Vidicon TV cameras developed for those flights had proved their utility and dependability. Instruments used in science experiments had also been successfully flown. Perhaps most important was experience gained in long-distance human-computer interaction that permitted response to glitches that too often arise in electronic equipment exposed to the rigors of space.

Voyager, though light in weight, had features that facilitated coping with many contingencies. In the 1800-pound spacecraft were six computers, eleven different science instrument packages, ²³⁸Pu thermoelectric generators furnishing about 400 watts of power, attitude-controlling devices, propellant for mid-course maneuvers and attitude control, two radios for sending information, and two for receiving it. Redundancy in the computers and radio receivers was later to prove crucial.

Two of the six computers were devoted to attitude control in three dimensions. Two were devoted to the scientific instrumentation. The remaining two were the brains of the vehicle. They were reprogrammable from Earth and could control the various functions of the spacecraft.

Less than 8 months after blast-off, defects that could have ruined the mission developed in the two radio receivers. One went dead. The second was found to be "tone-deaf." That is, it could not cope with the variations in frequency arising from a variable Doppler effect. In addition, the frequency that the receiver could recognize was influenced by temperature effects as small as 0.25°C. The JPL engineers diagnosed the problems and prepared computer tapes that slowly varied the sending frequency to compensate exactly for the disturbing effects. This restored good communication with Voyager. More than 11 years later, the receiver is still tone-deaf, but it can recognize the signals coming to it from Earth more than 4 light-hours away.

The Voyager 2 mission was one of the few times that a major space effort exceeded the promises made for it. JPL had only promised exploration of Jupiter and Saturn. But even before reaching Saturn the Voyager 2 team was making plans and developing capabilities for encounters with Uranus and Neptune. The images obtained from Jupiter and its satellites had been well received by the public. It was desirable to obtain good and many images of the two outer planets despite the low intensity of sunlight on them. At Neptune, light intensity is only 1/900 that at Earth. To obtain good pictures at the outer planets required a comparatively long exposure. But the attitude of the spacecraft tends to drift, leading to blurring of the image. The engineers devised and tested a way of minimizing this drift and radioed the necessary instructions to Voyager 2. Steps were taken to improve reception of image signals on Earth through expanding the array of radio dishes. A major improvement came from employing a redundant computer on the spacecraft. The memory and processor of the computer were used to compress the TV signals. A special computer code enabled Voyager 2 to send back the differences in light intensity from adjacent picture elements. This in effect enhanced the rate of communication of images by a factor of 2.5. Another improvement applicable to small satellites being passed at more than 40,000 miles per hour was to pan the camera by rotating the spacecraft while passing by. Instructions for this were communicated to the spacecraft which later implemented them at the appropriate moment.

One is left with a deep admiration for the quality of teamwork between humans and the spacecraft though they are nearly 3 billion miles apart. The humans safe on Earth have been able to use facilities of equipment and consultation to devise programming techniques that have wrung from Voyager 2 performance that was not imagined at blast-off on 20 August 1977.—PHILIP H. ABELSON

*Results from Voyager's encounter with Neptune and Triton will be published in a future issue of *Science*.