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THE POLAR BEAR SPACECRAFT

The Polar BEAR spacecraft was developed to measure auroral and ionospheric parameters and their effects on RF wave propagation. It provides coverage of the auroral oval in an area different from that covered from previous spacecraft, and the data gathered will complement the research being carried out by earlier programs. This article provides a technical description of the spacecraft and its initial in-orbit performance.

INTRODUCTION

The Polar BEAR spacecraft was launched on November 13, 1986, from Vandenberg AFB, Calif., into a nearly circular polar orbit of 1000-km altitude, with an inclination of 90°. The mission objective is to measure ionospheric parameters and their effects on RF wave propagation. Data gathered by the Polar BEAR spacecraft will provide coverage of the auroral oval in an area different from what was observed from previous spacecraft and will complement the data being gathered by a predecessor spacecraft, HILAT.[1]

This article describes the design, fabrication, test, launch, and post-launch activities of the Polar BEAR spacecraft. The spacecraft was designed, fabricated, and integrated by APL for the Defense Nuclear Agency and the Air Force Space Test Program.

SPACECRAFT DESCRIPTION

Design and fabrication of the Polar BEAR spacecraft[2,3] began with the acquisition of a Navy Navigation Satellite System (NNSS) spacecraft, Oscar 17, that had been on display in the Smithsonian Air and Space Museum. That acquisition, along with the use of design heritage from the HILAT spacecraft, formed the basic design of the Polar BEAR spacecraft. Because the spacecraft was to support scientific instruments that are not carried on the operational NNSS satellites, several new structural parts and electronics packages had to be designed and built. It was necessary to rebuild electronics units in situations where test and inspection records of the existing Oscar 17 hardware were unavailable or incomplete because recertification for high-reliability operation in the space environment was impossible without the original test data. Electronics units for which previous data still existed were recertified by test and inspection.

The Polar BEAR spacecraft has three complementary scientific instruments. The Auroral Imaging Remote Sensor (AIRS), a multiwavelength ultraviolet/visible scanner for imaging the auroral disk in daylight or darkness, was built for the Air Force Geophysics Laboratory by APL. The Beacon instrument, a coherent UHF/VHF/L-band source that allows the measurement of electron-generated scintillation, was built for the Defense Nuclear Agency by Stanford Research International, Inc. It serves a dual purpose because it is also phase modulated by data from the spacecraft scientific instruments. This method of data transmission allows recovery of the science data in the area of interest by ground stations located in the north polar region, without requiring onboard data storage. The magnetometer instrument, built by APL, also serves a dual purpose, being required for the initial attitude-stabilization maneuvers and providing complementary scientific information in the form of high-resolution vector measurements of the earth's magnetic field. Further details of these instruments are given in other articles in this issue.

The orbital configuration of the Polar BEAR spacecraft is shown in Fig. 1; the system block diagram is shown in Fig. 2. The spacecraft consists of structure, separation, and deployment mechanisms; a power subsystem; a command subsystem; a telemetry subsystem; an RF/antenna subsystem; and an attitude determination and control subsystem.

Mechanical Modifications

Starting with the basic Oscar 17 structure, payload mechanical lead engineer J. T. Mueller directed the effort to make extensive modifications to accommodate the instrument equipment. The center column, which is the principal load-bearing element of the structure, was removed and replaced with a similar titanium structure to handle the increased weight and bending moments. To accommodate the instrument packages and to provide a nadir-looking field of view, new structures (pedestal, penthouse deck, penthouse, and experiment deck) were added to the basic Oscar configuration.

An adapter structure, in the form of a truncated cone made of aluminum sheet metal with machined rings, is the interface between the spacecraft and the Scout's fourth-stage rocket. The forward (smaller) ring mates with the spacecraft pedestal, the juncture forming the separation plane. This joint is restrained during launch by friction provided by the preload in a V-shaped clamp-strap. The clamp-strap halves are fastened together with pyrotechnically initiated separation bolts.

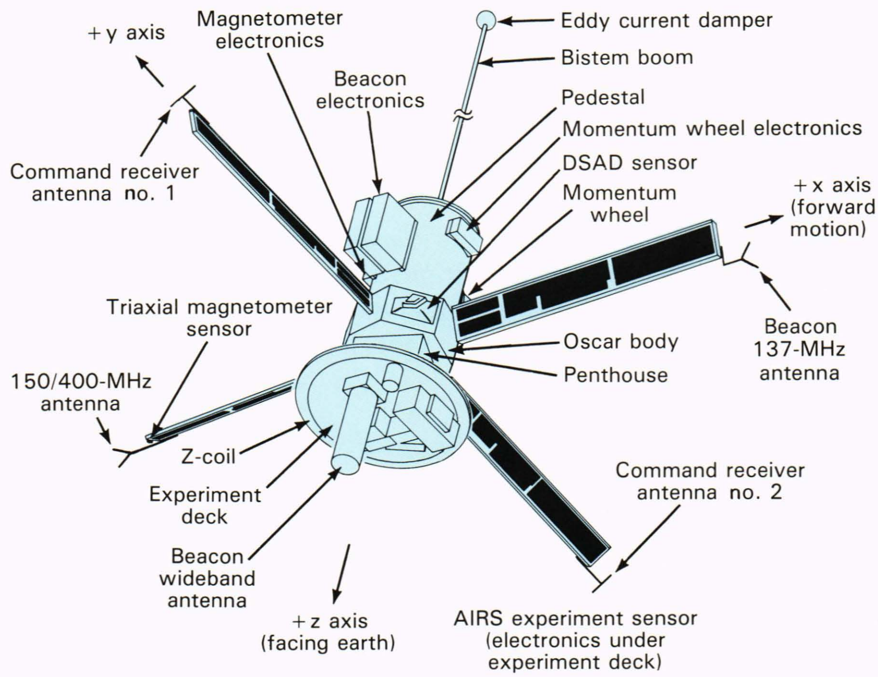

Figure 1—The Polar BEAR spacecraft orbital configuration showing the physical arrangement of its components. Forward motion of the spacecraft is along the +x (roll) axis; the +z (yaw) axis is in the direction facing earth. Pitch motion is about the y axis.

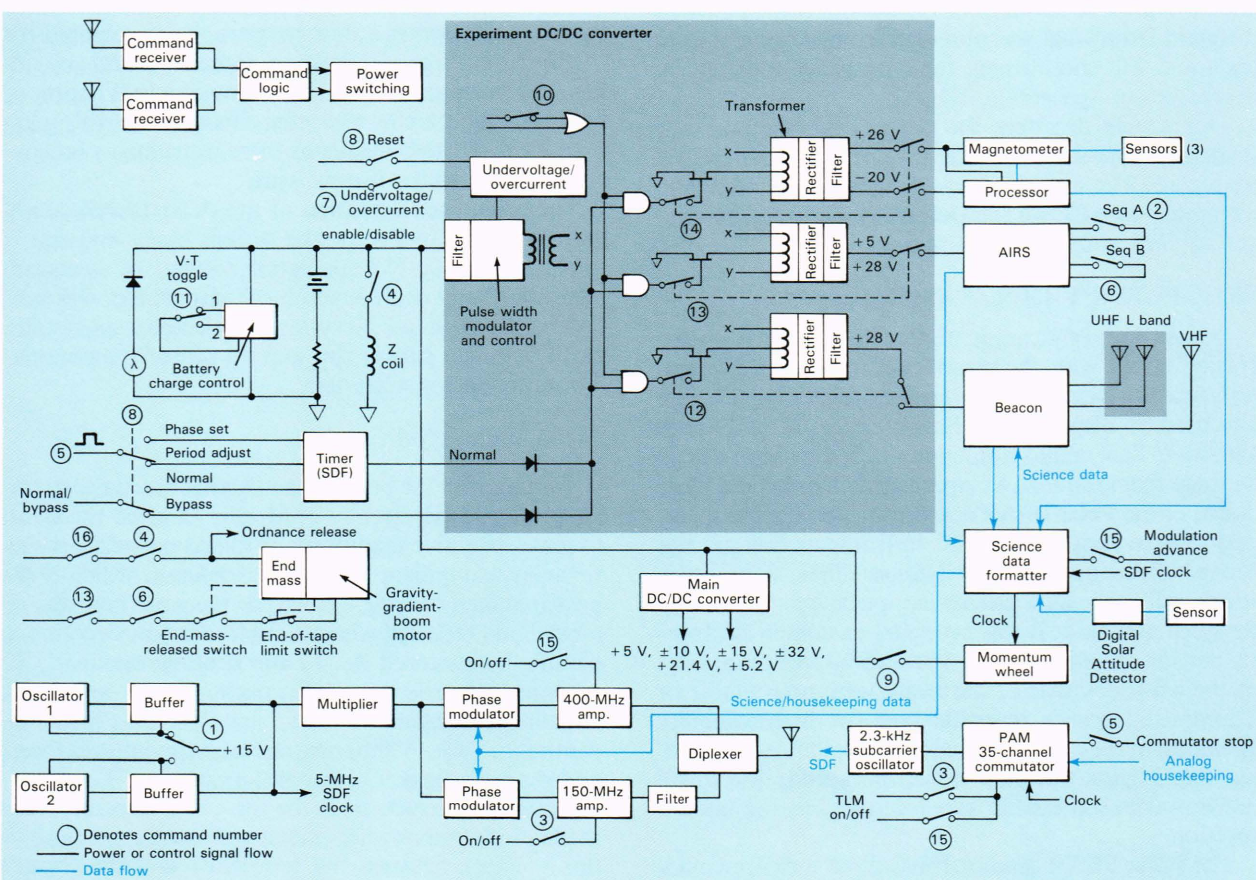

Figure 2—System block diagram of the Polar BEAR spacecraft.

Separation springs and a sublimation timer/switch assembly are also mounted in the adapter. The springs produce the force needed to provide a separation velocity of approximately 0.9 m/s from the Scout's fourth-stage rocket. The sublimation timer/switch assembly provides the signal to initiate separation from the Scout after orbit insertion and the signal to start the despin and solar-array-deployment sequence.

H. W. Wong and D. F. Persons performed a stress analysis on the designs and worked in coordination with the Scout launch vehicle contractor to ensure that the interfaces were correct and that the Polar BEAR spacecraft would be able to withstand the rigors of launch.

The mass properties of the Polar BEAR spacecraft are given in Table 1.

Table 1—Mass properties of the Polar BEAR spacecraft.

	Launch	*Orbit*
Weight (kg)	118.24	113.93
X_{cg} (m)	-6.27×10^{-3}	7.6×10^{-3}
Y_{cg} (m)	-1.14×10^{-3}	2.5×10^{-3}
Z_{cg}* (m)	0.371	0.085
I_{xx} (kg·m^2)	25.9	933.6
I_{yy} (kg·m^2)	25.6	936.4
I_{zz} (kg·m^2)	5.62	29.13
I_{xy} (kg·m^2)	−0.027	0.39
I_{xz} (kg·m^2)	−0.435	0.62
I_{yz} (kg·m^2)	−0.366	0.50

*From separation plane.

Thermal Design

The thermal design of the Polar BEAR spacecraft (directed by D. S. Mehoke) uses the same basic passive design approach used in the NNSS and HILAT programs. Temperature control depends on balancing the internal and external heat inputs.

As shown in Fig. 1, the spacecraft consists of an earth-facing platform and a zenith-facing pedestal mounted to the central Oscar structure. The low thermal conductivity in the Oscar body separates the structure into three relatively independent sections: the experiment-deck/penthouse area, the pedestal, and the Oscar body/main electronics. Heat dissipated in the experiment-deck/penthouse area is either leaked through the multilayer insulation blankets or radiated from the penthouse walls. The pedestal section is controlled in much the same way: heat is conducted from the electronics packages to the supporting structure and radiated out through the thermal blankets. Heat generated in the Oscar's main electronics is conducted to the mounting structure, through the battery assemblies, and radiated from the Oscar shell.

Most of the external surface of the spacecraft is covered with multilayer insulation blankets that, in general, are composed of 18 layers of 6.4-μm Mylar® with 25.4-μm Kapton® inner and outer layers.

Heat pipes were incorporated into the Polar BEAR thermal design to reduce temperature gradients between the battery assemblies. Because of the Oscar spacecraft design heritage, the battery cells are distributed around the periphery of the Oscar main electronics. The addition of the heat pipes reduces the temperature gradients by connecting the individual battery assemblies. There are four identical pipes, each constructed of an aluminum shell with ammonia as the working fluid.

The paint pattern of the Oscar was changed and waste heaters were added to improve thermal control. The all-white surface paint was changed to a combination of black paint and silver Teflon®. The optical properties of the new finish are much more stable than those of the white paint, reducing the uncertainty in the environmental heat loads. The waste heaters, which can be enabled and disabled by ground command, were added to the pedestal to dump excess heat during periods of maximum solar-array generation. Energy dumped into these heaters reduces the amount of heat that is dissipated in the batteries and reduces their temperatures.

Power Subsystem

G. A. Herbert, power system lead engineer, directed the design effort on the the Polar BEAR spacecraft power subsystem, which consists of a solar-cell array, a rechargeable nickel-cadmium battery, a battery charge controller, a main DC/DC converter, and an experiment DC/DC converter. The characteristics of the subsystem are presented in Table 2.

The solar array used for the Polar BEAR spacecraft consists of the refurbished panels obtained from Oscar 17. Four panels with cells on both sides are deployed in a cruciform shape after separation from the Scout and despin have occurred. Each panel consists of three circuits: main, boost, and automatic temperature control. For the Polar BEAR spacecraft, these circuits are wired to the spacecraft's main power bus. Solar-array power at the battery (for the expected solar aspects) ranges from

Table 2—Characteristics of the Polar BEAR spacecraft power subsystem.

Solar array	Four panels: 6688 N/P cells total Each cell: 2×2 cm, 0.1 Ω-m resistivity, 1.52×10^{-4} m Microsheet® cover glass
Unregulated bus voltage	12.2 V maximum, 10.7 V nominal, 8.0 V minimum
Power available	35–50-W orbit average
Battery	Eight series-connected cells; each cell, 12 A·h; total capacity, 120 W·h
Charge control	Temperature-compensated linear shunt regulator

40 to 50 W at the beginning of life and is expected to be in the range of 37 to 47 W after a 3-year exposure to orbital conditions.

The battery is distributed about the interior of the spacecraft, with two cells located in each quadrant of the main body. This presented a charge-control problem because the battery cells are subject to varying heat inputs (and hence varying temperatures), depending on the orientation of the spacecraft to the sun. The problem was solved by adding heat pipes that link the individual cells thermally and keep them within 2°C of one another throughout all orientations.

Battery-charge control is performed in a manner similar to that used on HILAT; however, several changes were made to improve the system's effectiveness. The charge-control system senses the temperature and voltage of the battery and accordingly shunts array current away from the battery to reduce overcharge. The Polar BEAR spacecraft normally operates on the lower of two voltage–temperature curves; the higher curve is available if it is felt that the battery is not being fully recharged.

The main DC/DC converter, a new design executed by D. Kusnierkiewicz, provides conditioned power to the spacecraft subsystems. It contains a low-voltage circuit to protect the battery automatically if it is inadvertently depleted and the bus voltage falls below 6 V. Operation resumes when the battery is recharged to above 8 V. This provides the capability to recover from a charge-deficiency situation by being able to command the removal of unneeded loads while the system further recovers. It also allows operation of the spacecraft in the event that a single battery cell becomes shorted.

An experiment DC/DC converter, designed and developed by J. E. Tarr, provides regulated power to the instruments. It contains an undervoltage–overcurrent circuit that will shut down the converter if the battery bus voltage falls below 8 V or if an overcurrent condition is detected. The protection circuitry in the experiment converter does not allow automatic recovery and requires that a command be sent to effect a reset and restore proper operation. It is also possible to operate the experiment converter with the protection circuit disabled.

Command Subsystem

The Polar BEAR spacecraft command subsystem is based on the NNSS Oscar spacecraft in that it uses the same format and protocol for commanding. However, to accommodate the requirement for additional control of the spacecraft, B. C. Moore (lead engineer) and J. E. Kroutil designed the unit so as to provide a command capability equivalent to two Oscar spacecraft command subsystems. In addition to providing 16 basic commands instead of 8, the Polar BEAR spacecraft's commands are arranged so that most of them perform more than one function.

There is no delayed or data command capability. Commands are executed in real time using RZ-FSK tones that amplitude modulate a VHF carrier. The signal is received by each of two dipole antennas mounted on opposing solar panels and is demodulated by the command receivers. Each receiver, which is connected to only one of the command antennas, demodulates the signal and provides the recovered tones to the bit detector in the command logic. The outputs of the two receivers are summed at the input to the bit detector in order to improve command reception, since nulls in the antenna patterns are reduced in the summed signal.

The command logic decodes the tone sequences and, if the address field is correct, executes the command. Most of the signals from the command logic are sent to the power switching unit to effect the transfer of relays that switch power and signals within the spacecraft; however, several level and pulse signals go directly to the users.

The power switching unit implements the specific control functions necessary to operate the Polar BEAR spacecraft. It contains isolation circuitry (to allow separation of power and signal grounds) and relay drivers, and also provides relays connected in a unique contact configuration necessary to switch power for users who do not have relays in their own packages.

Telemetry Subsystem

There are two independent data return systems on the Polar BEAR spacecraft: one for housekeeping (engineering) data and one for science data. Under the guidance of lead engineer R. F. Conde, it was determined that two separate systems maximized the use of existing Oscar spacecraft and ground hardware and minimized the amount of new design needed. In day-to-day maintenance and control (performed by the Naval Astronautics Group), the Polar BEAR spacecraft looks much like an Oscar spacecraft. However, all science data are collected by L-band-equipped receiving stations, similar to the manner in which HILAT data were collected.

The housekeeping telemetry subsystem was recovered from Oscar 17 and requalified for flight. It consists of a 35-channel analog commutator that provides a multiplexed pulse amplitude modulation (PAM) data signal to a 2.3-kHz subcarrier oscillator at the rate of approximately 1.6 channels per second. The subcarrier oscillator is frequency modulated at $\pm 6\%$ (nominal) by the PAM signal and produces an output voltage that causes a phase deviation of $\pm 60°$ peak in the output of the 150-MHz (primary) or the 400-MHz (backup) transmitter.

Several types of data (voltages, currents, temperatures, and discrete signals) are sampled by the housekeeping system to indicate the state of functions throughout the spacecraft. All signals are converted to voltages and are attenuated to ± 0.25 V before they are multiplexed by the commutator and applied to the subcarrier oscillator. In order to increase the effective number of telemetry points, several one-time events (such as solar-panel deployment) produce biased readings of the primary function until the one-time event has occurred.

Digital science data are collected from the instruments, formatted by the science data formatter, and sent to the Beacon L-band transmitter in Bi-Phase-M format for transmission to the ground. In addition to the instrument data, the data stream contains data from the Digital Solar Attitude Detector and other digital engineering data.

The science data formatter contains circuitry that generates clocks and readout gate signals used by other subsystems and instruments to transfer data to it. It also contains the Power Management Timer circuitry, designed by P. Eisenreich, which conserves and controls power to the instruments. Power is applied to the instruments only when the spacecraft is above about 45° N latitude—the area of scientific interest and also the area where the ground stations can recover the data, thus eliminating the need for on-board data storage. The power management timer has an adjustable counter set by command from the ground to cause its period to match the orbit period of the spacecraft. After the counter period is adjusted, another command is sent to set its epoch. In addition to this primary mode, it is possible to set the power management timer's epoch to power the instruments over any quarter of the the Polar BEAR spacecraft's orbit. The power management timer can also be placed in an alternate orbit mode where it will power the instruments for 25% of an orbit, every other orbit, should power generation and usage so dictate.

The science data formatter contains the circuitry that implements the modulation mode command (see Table 3) to control the mode of the power management timer and to route science and housekeeping data to the appropriate downlink transmitter.

RF Subsystem

R. K. Huebschman served as lead engineer for the RF subsystem, which provides the input signal to the command subsystem, provides a highly stable frequency source, and produces residual carrier phase-modulated signals to transmit the spacecraft housekeeping data and backup science data. It includes redundant command receivers, redundant 5-MHz oscillators, a frequency multiplier/phase modulator, 150- and 400-MHz power amplifiers, transmitter filters, a diplexer, and antennas.

The command receivers are a tuned RF design originally implemented by G. R. Seylar for the NNSS NOVA spacecraft. The circuitry was repackaged to accommodate a new hybrid microcircuit package configuration. Both receivers operate on the NNSS command frequency and have a -3 dB bandwidth of 35 kHz and an input dynamic range of -95 to -35 dBm.

The oscillators operate on a frequency that is offset 141 parts per million below the nominal frequency of 5 MHz to avoid interference with the operational NNSS spacecraft. (J. L. Wilcox was responsible for the effort to repackage and test the oscillators.) Signals are provided to the science data formatter and to the 150-/400-MHz transmitters. Only one oscillator is powered and operating at any time; selection of the operating oscillator is made by command from the ground.

The frequency multiplier/phase modulator receives the 5-MHz signal from the oscillator, multiplies it to 50 MHz, and splits it into two channels. Data from the science data formatter are then phase modulated onto the two channels and sent to the 150- and 400-MHz power amplifiers.

The 150-MHz power amplifier, obtained from Oscar 17 and requalified for use on the Polar BEAR spacecraft, is used only to transmit housekeeping data and provides an output power level of approximately 0.5 W. The 400-MHz power amplifier, a new design, has a power output of approximately 0.75 W and transmits data in accordance with the operating mode of the spacecraft as shown in Table 3.

The 150- and 400-MHz signals are filtered and combined in a diplexer before being sent to the dual-frequency dipole 150-/400-MHz antenna. The diplexer contains isolators to protect the power amplifiers from high voltage-standing-wave ratios that are encountered when the antenna is folded in the launch configuration. Major contributions to the design, fabrication, and test of the RF subsystem were made by R. A. Reiter, R. S. Bokulic, and W. T. T. Gray.

The 150-/400-MHz antenna transmits left-hand circular polarization and provides coverage over the visible earth. This design provides enough effective radiated power to allow reception of data when the spacecraft is in a random orientation prior to gravity-gradient stabilization. The loss of data due to antenna pattern nulls below -15 dB (relative to an isotropic antenna) is minimized by receiving the signal with a 18.3-m parabolic antenna on the ground. The Polar BEAR spacecraft antenna design was performed under the direction of R. K. Stilwell.

Table 3—Modulation mode sequence of the Polar BEAR spacecraft.

Step	*400-MHz Data*	*L-Band Data*	*Mode*
1	Off	Science	Normal
2	Science	Unmodulated	Science backup
3	Off	Science, alternate	Science, alternate orbits
4	Housekeeping	Science	Housekeeping backup

Attitude Control and Determination

The Polar BEAR mission requires three-axis stabilization and control to a local vertical system, with roll, pitch, and yaw angles less than $\pm 10°$ (3σ). These requirements are implemented by using a momentum wheel, an electromagnet, a gravity-gradient boom, and an eddy-current-damping end mass and by performing the stabilization in two phases.

During phase one (after separation from the Scout launch vehicle), primary despin and erection of the solar arrays are achieved by the "yo-yo" despin system. The momentum wheel is then uncaged and powered, thereby stabilizing the spacecraft in yaw. Residual motions are removed by two hysteresis rods mounted in the solar-array panels. After the motions have subsided, an electromagnet is powered to achieve magnetic stabilization with the spacecraft tumbling in pitch at two revolutions per orbit.

Phase two is initiated when the attitude angles and rates resulting from the phase one maneuvers have been damped sufficiently. It is effected by gravity-gradient stabilization, which is accomplished by erecting the bistem "zipper" boom and eddy-current-damping end mass and by removing power from the electromagnet at an appropriate position in the orbit. This causes the spacecraft to tumble at one revolution per orbit; i.e., the instrument platform remains pointed toward earth, with its z axis aligned along the gravity vector. Damping of the remaining motion is provided by the eddy-current-damping end mass and by the hysteresis rods mounted in the solar panels.

The momentum wheel is launched in a caged position to avoid damage to its bearings. It has an angular momentum of 2.4 N·m·s at its nominal spin rate of 2000 rpm and is mounted so that when running, its momentum vector is aligned parallel to the spacecraft's pitch axis.

The electromagnet (Z-coil) consists of 126 turns of number 18 aluminum magnet wire wound around the experiment deck. Under nominal conditions it produces a magnetic dipole of 54 At·m^2 (ampere turn·$meter^2$) aligned parallel to the z axis of the spacecraft. As indicated above, it is used only briefly during the phase one attitude maneuvers and is then powered off for the rest of the mission. The magnetic dipole produced is large enough to effect inversion in the event that the spacecraft "captures" with the instrument platform pointing away from (instead of toward) earth.

The boom assembly consists of two reels of interlocking beryllium-copper tapes that deploy from the reels and are meshed in a zipper-like fashion to form a semirigid tube that extends to 18.3 m. The eddy-current-damping end mass, mounted on the end of the boom, provides a dipole moment of approximately 29 At·m^2 and develops a damping coefficient of approximately 0.007 N·m·s/rad.

The attitude is determined by measuring the earth's magnetic field and the angle between the spacecraft and the sun and transmitting the data via the science telemetry link. The magnetic field measurements are made by a triaxial sensor (mounted on the end of one solar panel) and the magnetometer electronics assembly, with an overall accuracy of ± 300 nT. Three sun sensors and an electronics assembly measure the sun's direction with an accuracy of $\pm 1°$. These two measurements provide a computed attitude accuracy of $\pm 1°$, which degrades as the magnetic field vector and the spacecraft-to-sun line become nearly parallel. It is possible to obtain a coarse measurement of attitude by using lower resolution magnetic field data transmitted via the housekeeping telemetry.

The effort to design, fabricate, and test the system was guided by W. E. Radford, with major support from W. L. Ebert, F. F. Mobley, W. A. Swartz, L. Scheer, J. F. Smola, B. A. Phillips, J. W. Hunt, and C. E. Williams.

FABRICATION

It was necessary that the Polar BEAR spacecraft be fabricated so as not to produce volatiles that would outgas in orbit and degrade or damage the optical properties of the AIRS instrument. R. M. Dodd, technical administrator, and R. D. Brantley, reliability and quality assurance engineer, worked with APL's Technical Services Department to ensure that the proper materials and correct processes were available and properly applied. After individual units had been assembled and tested, they were "baked out" in a thermal vacuum chamber to remove additional volatile materials. The units were then placed in controlled storage until they were required for integration.

In addition to the above measures, the AIRS instrument was kept under a positive gaseous nitrogen purge at all times to further reduce the possibility that its optics would be degraded or damaged by contaminants.

The success of these efforts was indicated when the entire spacecraft was subjected to thermal vacuum testing and a vacuum of $<10^{-4}$ Pa was achieved approximately one day after vacuum chamber pump-down was started. Additional measurements taken during the remainder of the thermal vacuum test with a residual gas analyzer and quartz-crystal microbalance supported the initial observation that the goal of making the Polar BEAR spacecraft a "clean" spacecraft had been achieved.

INTEGRATION AND TESTING

Integration of the Polar BEAR spacecraft started in November 1985, under the direction of payload electrical lead engineer W. E. Ray. (This was the first APL spacecraft to be entirely assembled and tested in APL's Kershner Space Building.) It was recognized that in order to meet the launch date it would be necessary to start integration using several packaged breadboards (electrically identical to the flight units but not a mechanical "form and fit") and engineering models to gain advance experience with the performance and interaction of the spacecraft subsystems while awaiting qualification and delivery of the flight electronics packages. The spacecraft was partially assembled (Fig. 3) into three major pieces: the pedestal/Oscar outer shell, the main Oscar electronics, and the penthouse/experiment deck. This allowed the refinement of electrical test procedures, using ground support equipment designed and developed by D. D. Stott, J. F. Bogdanski, R. K. Burek, and J. M. Roberts, and provided early identification of interface problems, which could then be corrected without major disassembly of the spacecraft.

Upon completion of integration, the Polar BEAR spacecraft underwent extensive testing at APL under various environmental conditions. A ground station test was conducted to verify compatibility with both the APL and the Naval Astronautics Group stations. Alignment measurements were performed to determine the relative positions of the attitude-subsystem sensors and the experiments, thus providing knowledge of their field of view from orbit. Electromagnetic compatibility testing (Fig.

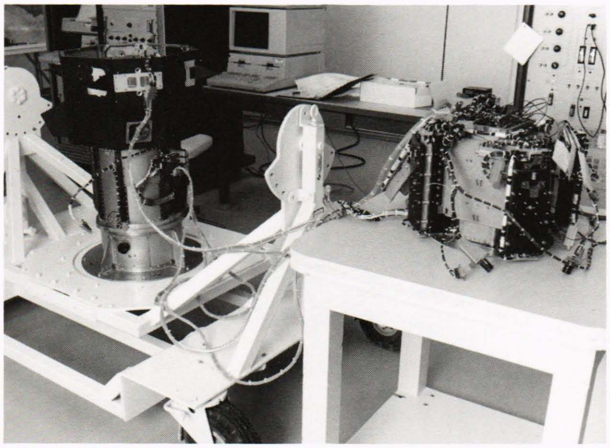

Figure 3—The Polar BEAR spacecraft in the early stage of integration.

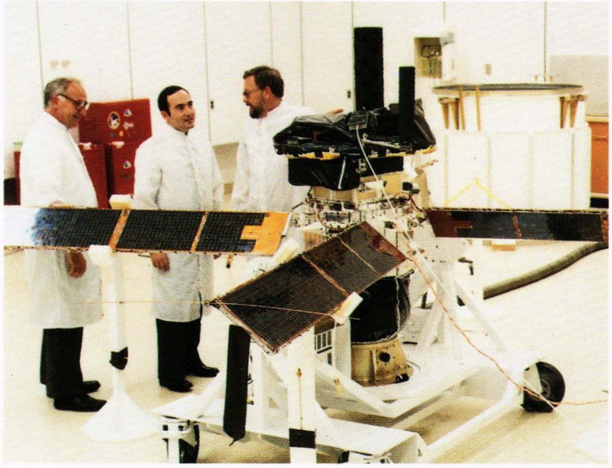

Figure 4—D. G. Grant, R. W. Roberts, and M. R. Peterson (left to right) discuss electromagnetic compatibility testing of the Polar BEAR spacecraft. The spacecraft is shown in a pseudo-orbital condition.

4) was performed with the spacecraft assembled in the launch and orbital configurations in order to identify any incompatibilities between electronics assemblies. Vibration and deployment testing (Fig. 5) was performed to ensure that the spacecraft would survive the launch environment. Thermal vacuum testing provided confirmation of the thermal design of the spacecraft and its expected performance in orbit. Magnetic calibration and mass property measurements were performed at the NASA/Goddard Space Flight Center.

The Polar BEAR spacecraft was transported from Andrews AFB, Md., to the launch site at Vandenberg AFB, Calif. At the launch site, the spacecraft was again tested to verify system performance. It was mated and spin-balanced with the Scout's fourth-stage rocket motor and finally mated to the rest of the Scout launch vehicle.

LAUNCH/POST-LAUNCH ACTIVITIES

The Polar BEAR spacecraft was successfully launched from Vandenberg AFB on November 13, 1986, at 1623 PST (November 14, 1986, 0023:02 UT) on a NASA Scout rocket. The spacecraft at lift-off weighed 118.24 kg, and the orbit achieved was 1012 km (apogee) by 970 km (perigee) with an inclination of 89.55°, resulting in a nodal period of 104.99 min.

Initial post-launch activities[4] were carried out at the APL Satellite Tracking Facility. Phase one attitude-stabilization maneuvers began during the first pass viewed by the facility, when the health of the spacecraft was confirmed, and the momentum wheel was uncaged and power was applied to prepare for magnetic stabili-

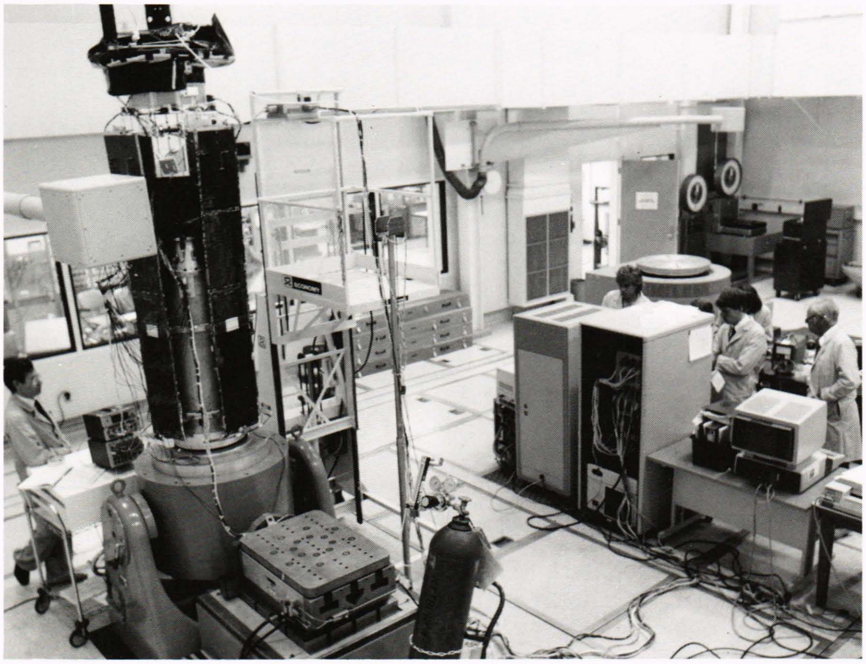

Figure 5—Vibration testing of the Polar BEAR spacecraft. Ground support equipment is at the right of the spacecraft.

zation. Within one day the spacecraft dynamics were suitable for magnetic stabilization, which was initiated by powering on the Z-coil electromagnet. On November 16, the attitude motions of the Polar BEAR spacecraft were determined to be low enough to perform gravity-gradient stabilization; therefore, the boom was extended and the Z-coil was powered off. (The unusually rapid transition to gravity-gradient stabilization is attributed to additional damping provided by the eddy-current damper.) Subsequent to the attitude stabilization maneuvers, the Polar BEAR spacecraft was observed to have motion of less than 5° peak in roll and pitch, with yaw ranging from 3 to 12° peak.

The spacecraft's modes were tested functionally, and it was placed in an operational state by adjusting the period of the power management timer to correspond to the orbital period. During initial operations, battery temperatures were noted to be higher than expected, but they decayed to acceptable levels after the spacecraft became stable and entered eclipsed orbits. The solar-array current observed in orbit indicates that the arrays are performing at their estimated level. Experiment check-out was performed successfully and no anomalies were noted.

On December 12, 1986, the Polar BEAR spacecraft was declared operational, and control was transferred to the Naval Astronautics Group at Point Mugu Naval Air Station, Calif.

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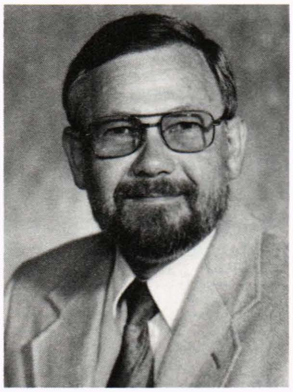
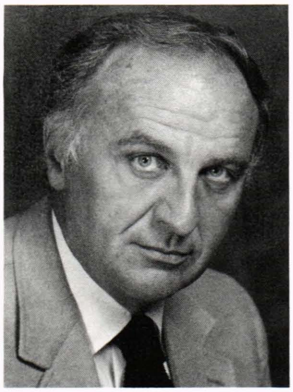
THE AUTHORS



MAX R. PETERSON is a native of Kansas and holds B.S. (Kansas State University, 1961) and M.S. (The Johns Hopkins University, 1968) degrees in electrical engineering. He joined APL in 1961 and worked in the Polaris Program but left in 1962 to work with Texas Instruments Co. He returned to APL in 1964 as an engineer in the Space Department's Space Telecommunications Group, where he supervised the Data Systems Design Section from 1969 until 1975. He was been involved with telemetry data instrumentation and overall telemetry system design for near-earth spacecraft and was telemetry system lead engineer for the Small Astronomy Satellite series. During 1975–1980, Mr. Peterson worked on the Global Positioning System package used for satellite navigation. He worked on the AMPTE/CCE spacecraft program as ground support equipment lead engineer and was appointed assistant program manager in 1983. Mr. Peterson was the Polar BEAR spacecraft system engineer. Since the launch of Polar BEAR, he has been involved in the proposal preparation for a follow-on mission. He is a member of the APL's Principal Professional Staff and is a staff engineer in the Space Department's Digital Flight System Group.



DAVID G. GRANT received an M.A. degree in applied mathematics in 1966 from the University of Maryland. He joined APL in 1959 and worked as an engineer on the Typhon Weapon System. He later developed electro-optical signal processing techniques for advanced radar systems. He became associated part-time with APL's biomedical engineering program in 1967 and was principal investigator on a 3-D X-ray imaging system that received the IR-100 outstanding engineering development award in 1969. Mr. Grant worked in the Submarine Technology Division before accepting an interdivisional appointment to the Johns Hopkins School of Medicine in 1975 as director of Radiation Therapy Physics. In 1978, he was appointed director of the Division of Clinical Engineering. In 1982, he returned to full-time duties at APL in the Space Department, where he is program manager of the Polar BEAR Spacecraft Program. Mr. Grant was appointed to the Principal Professional Staff in 1970 and is an associate professor of biomedical engineering in the School of Medicine.