WILLIAM McCLOSKEY

THE FLIGHT OF POLAR BEAR: A SUCCESSFUL SATELLITE PROGRAM GROWS FROM PARTS AND DETAILS

Early one morning in July 1984, a truck from The Johns Hopkins University Applied Physics Laboratory pulled up beside the Smithsonian Air and Space Museum in Washington, D. C. The doors had not yet opened to the public, but the streets were already crowded with tentative tourists as four APL men carrying wire cutters joined staff maintenance people inside. They walked through the main gallery, past the moon rocks, rugged space capsules, and towering booster rockets that proclaim the nation's accomplishments in manned space flight, and into a black-ceilinged hall with satellites suspended like planets over a relief model of the earth's oceans and land masses. The satellites, some with exotic shapes and bristling antennas, symbolized the cornucopia of scientific data that man has gained in nearly three decades of unmanned space probes. This was a practical visit rather than a contemplative one, however, and a cherry-picker truck followed the men.

Within 20 minutes, APL technicians coached by David Grant, program manager of a new project called Polar BEAR, had ridden the cherry-picker bucket to the ceiling. They cut down Oscar-17, a suspended satellite that, with its four long solar panels emanating from a white hexagonal body, resembled the head of a windmill. Oscar-17, a navigational satellite built in 1963, had been a backup spacecraft that was never used because of the success of other launches. When the Smithsonian Air and Space Museum opened in 1976, APL donated Oscar-17 for permanent display. Now, in a time of tight budgeting, the spacecraft, complete with working solar panels, was being reclaimed to become a new scientific satellite that would be called Polar BEAR. William Buchanan of APL's External Relations Group, who had arranged the original gift, negotiated with a sympathetic Smithsonian management to exchange the Oscar-17 for a Transit 5A model that had been part of a permanent APL institutional exhibit.

On November 13, 1986, the object of the Smithsonian exchange entered a 535-nmi (991-km) polar orbit, launched aboard a Scout G-1 rocket from Vandenberg Air Force Base in California. The Polar BEAR—Polar Beacon Experiment and Auroral Research—satellite had been developed by APL and sponsored by the Defense Nuclear Agency and the U.S. Air Force's Space Division. It carried several experiments designed to improve communications over the earth's polar regions. At high latitudes, solar flares and auroras routinely disrupt the transmissions from a multitude of satellites orbiting overhead for purposes of communications, navigation, and meteorology. They interfere as well with some ground communications and radar signals. The Polar BEAR satellite is expected, during one year of mission time, to provide data that will lead to several new techniques for alleviating the disruptions.

THE POLAR BEAR EXPERIMENTS

The scientific mission of Polar BEAR continues the work that began aboard the HILAT (high-latitude ionospheric research) satellite built by APL for the Defense Nuclear Agency and launched in June 1983. HILAT carries a wide range of scientific instruments, including multifrequency radio beacons, energetic electron sensors, cold-plasma detectors, a magnetic field experiment, and an ultraviolet (UV) auroral imager (see the *Johns Hopkins APL Technical Digest,* Vol. 5, No. 2 (April–June 1984)). The HILAT UV auroral imager obtained the first picture of auroral emissions in full sunlight. That instrument has stopped providing images, but all other experiments on HILAT are still working well after almost four years in orbit.

The success of the HILAT auroral imaging system led to Polar BEAR, which carries an advanced-design, multichannel UV auroral imaging system called AIRS for Auroral Ionospheric Remote Sensor. Polar BEAR also carries a high-resolution magnetic field experiment and a multifrequency radio beacon. The simultaneous data from HILAT and Polar BEAR will be combined to provide correlative information on the same phenomena.

Inspecting the satellite body after it emerges from the thermal vacuum chamber at APL after 22 days of extensive temperature tests under the vacuum conditions of space. L-R: Bill Wilkerson, Ted Mueller, Bill Leidig, and Dave Glock. (Photographs by the author.)

The AIRS experiment, designed at APL under the direction of Fred Schenkel and Bernard Ogorzalek, was sponsored by the Air Force Geophysics Laboratory, Hanscom Air Force Base, Mass. The principal investigators are Ching Meng of APL and Robert Huffman of the Air Force Geophysics Laboratory. AIRS is a scanning device operating at multiwavelength UV and visible light. It produces day and night images of the auroral oval that encircles the regions above the poles. (The aurora itself is the product of light emissions caused by electrically charged particles bombarding the earth's atmosphere from space.)

The Magnetic Field Experiment, designed and built at APL under the direction of Fred Mobley, Peter Bythrow, and Wade Radford, provides high-resolution readings of the earth's magnetic field. Bythrow and Larry Zanetti of APL were principal investigators. The instrumentation transmits back the data necessary to determine the orientation of the Polar BEAR spacecraft. The experiment combines a three-axis vector magnetometer with a digital data processor.

The Beacon Experiment, developed by SRI International's Radio Physics Laboratory under the direction of Robert Livingston and James Vickery, measures scintillation in the earth's ionosphere above the polar regions that are related to auroral phenomena. The principal investigator was Leon Wittwer of the Defense Nuclear Agency (who also served as program sponsor of the entire Polar BEAR project). Beacon contains three transmitters operating at VHF, UHF, and L-band frequencies. The L-band transmitter also provides the satellite telemetry link to the ground.

RESEARCHING A FORMER SATELLITE

When they removed the spacecraft from the Smithsonian ceiling, the APL team hoped that it was "fully loaded"—that its original instrumentation had remained inside. This would have saved a number of basic fabrication expenses running in the millions of dollars. Those at APL who had prepared the Oscar for donation eight years before were not able to recall whether it had gone with a complete package of electronics instrumentation.

"We were hopeful," recalls Grant, "but we didn't know what to expect." The light weight of the spacecraft was the first giveaway. "We quickly opened it up," said Grant. "There were no electronics. All we had was the basic shell of a spacecraft—what amounted to a chassis—and the solar panels."

Grant and program scientist Mike Griffin (now with American Rocket Co.) returned to APL, traced out the history of Oscar-17, and determined that much of its electronics still existed somewhere. A stockroom inventory yielded nothing. Further investigation pointed the trail toward RCA, which had assumed responsibility for manufacturing the Oscar navigation satellites after APL had developed them. It turned out that APL had shipped all spare subsystems to RCA at the time of transfer. The RCA people were very cooperative, according to Grant, and sent down the record books that contained serial numbers through which the old inventory might be traced. They found several of the missing Oscar-17 subsystems. Others never surfaced. However, the recovered subsystems, along with the spacecraft frame and solar panels, represented enough saving over the cost of an entirely new satellite that the sponsor approved the mission.

STEPS IN BUILDING A SATELLITE

The Polar BEAR program proceeded in orderly fashion under Grant, who as program manager directed the overall effort. Max Peterson, program systems engineer, held primary responsibility for functional performance and for the overall design and fabrication effort. Assembly and testing of the spacecraft were conducted by J. T. ("Ted") Mueller, payload mechanical engineer, and William Ray, the payload electrical engineer.

The construction of a spacecraft follows a well-defined sequence of steps. It begins with determining the satellite's performance requirements and designing a functional spacecraft system to do the job. Subsystem specification and design follow, then fabrication and qualification testing. The completed subsystems are finally integrated into the basic structure of the spacecraft.

Integration starts with installing the power subsystem. The radio frequency (RF) subsystem follows, then the command subsystem ("so you can tell it what to do," according to Peterson), then the telemetry ("so you can see if it did what you told it to do"). Adding the attitude subsystem and the experiments completes integration.

Once the spacecraft is intact, qualification testing begins to ensure the compatibility of the systems with each other and with the ground station that will operate them. It must also be demonstrated that the subsystems can withstand the rigors of the launch and space environment.

The spin and mass properties tests are a vital step because the spacecraft may develop a wobble during launch if it fails to balance properly. For Polar BEAR, those tests were performed at the NASA Goddard Space Flight Center, along with tests of the magnetic sensors. After its return from spin and magnetics testing, the spacecraft receives a final "baseline" electrical test and then, after being shipped for launch, undergoes an extensive regime of field testing.

It was decided early in the fabrication process that Polar BEAR would be a "clean" spacecraft. This commitment at the outset by the entire Polar BEAR team meant selecting materials with great care and then striving in all stages of fabrication to avoid leaving contaminants. (Fingerprints were particularly to be avoided, since the oils they can leave might "outgas" during space flight and degrade the ultraviolet and infrared optical properties of the scan mirror of the AIRS experiment.)

Maintaining cleanliness was the responsibility of Richard Brantley. As reliability and quality assurance engineer, he designated materials with low out-gassing potential (e.g., for potting compounds and lacing cords) and supervised clean room procedures. As a final assurance of cleanliness, all fabricated components were placed in vacuum conditions at an elevated temperature for several days.

Brantley's quality assurance group performed a variety of analytical and monitoring functions on Polar BEAR, including specification, procurement, and integrity verification of all electrical parts to ensure their reliability performance during the mission. This work required constant monitoring—of the stress on parts, of fabrication, of procedures, and of test methods. The group also conducted reliability analyses of some circuits.

BUILDING THE STRUCTURE AND THE ELECTRONICS

The former Oscar satellite returned to APL from the Smithsonian essentially an outer shell that required extensive structural modifications to support the Polar BEAR components. A design team under Mueller's direction performed the retrofitting. They added a "penthouse" and an "experiment deck" to the top of the satellite frame to house the AIRS experiment and other instrumentation, and added a "pedestal" on the bottom to support the momentum wheel, the magnetometer, and the Beacon Experiment along with their electronics. Other modifications included a new titanium center column to provide necessary structural support for the spacecraft subsystems and experiments.

The electronic subsystems integration proceeded in a parallel effort directed by Ray. The RF subsystem was developed under Dick Huebschman, the command subsystem under Bruce Moore and Jerry Kroutil, the telemetry under Dick Conde, and the ground support equipment under Joe Bogdanski and Ron Burek.

A year after the Smithsonian visit, Ray's systems assembly at APL resembled more the trailings of a yard sale than a spacecraft. It lay spread over three tables in one of the clean rooms—a congeries of parts and breadboards, all connected by a smorgasbord of wires.

Ray was taking a prudent risk. In the usual assembly method, subsystems go into the satellite frame module by module, and then the complete system is tested with everything in place. Under the constraints of time and expense, Ray devised a different procedure based on the fact that some of the hardware was already available and had been retested upon arrival back at APL. He substituted breadboard units able to provide comparable signals for each system not yet represented by flight hardware. This meant that the systems already built could be tested for their functions within a simulated spacecraft.

The gamble was successful. "As we completed each piece of hardware," said Ray, "we'd substitute it for the breadboard, just plug it in. I didn't have to wait for the last piece to arrive before I could start the tests." Most of the breadboard units, built by APL's Microelectronics Group, were about six times the actual size of the pieces they represented, but "electrically they were exactly the same as flight hardware—they had the same electrical interface." The method saved approximately six months of test time.

A CLEAN SPACECRAFT IN THERMAL VACUUM

The Polar BEAR team completed assembly and integration in May 1986. In late June, approximately two years after the Smithsonian visit, the spacecraft entered a thermal vacuum chamber at APL for 22 days of extensive temperature tests under the vacuum conditions of space. Among those monitoring several phases of the tests were Douglas Mehoke, lead thermal engineer, and Gregg Herbert, lead power system engineer.

The computer software for the power subsystem test, written by Herbert, simulated the multitude of conditions the satellite would encounter in orbit, ranging from positions in full sunlight to eclipse behind the earth. As an example of one situation, Herbert explained, there would be no array power in the eclipse mode, when the satellite's solar panels were not activated by sunlight; at the same time, the subsystems and experiments would continue to need power to operate.

Tests showed the level of power drain on the satellite batteries, which in turn indicated the amount of time the experiments could operate during eclipse (e.g., when the satellite's orbit took it through the earth's shadow). The information derived from the simulation was then used by Mehoke to recommend the programming cycle of the experiments and to control physically the temperature distribution within the spacecraft with thermal blanketing materials. When the thermal vacuum tests were completed on July 18, the spacecraft returned to the clean room area. Here Mehoke began the modifications that he had determined were appropriate, by taping and relocating strips of black thermal material around various surfaces.

The thermal vacuum tests also verified spacecraft cleanliness. According to Peterson, three factors indicated the clean condition: "First, we were able to pump down the chamber very rapidly to an extremely low pressure. Then, when we looked at the residual gas component in the chamber there were very few spectral lines, indicating that the amount of materials was quite low." Readings from a quartz crystal microbalance (which measures the amount of condensation on a quartz oscillator) provided the third indicator. The readings showed a very low release of contaminants.

FINAL CEREMONIES

During all the design and development periods of Polar BEAR, through the final weeks before shipping the spacecraft to Vandenberg Air Force Base in Lompoc, Calif., for launch, the spacecraft team met each Tuesday morning to compare notes and discuss the progress and problems in various departments. Max Peterson usually presided in an informal atmosphere. Some 10 to 24 people attended, depending on their availability.

Tuesday, August 12, 1986, 0900, regular meeting: Robert Dodd, technical administrator of the project (a contractor with Bendix), listed the members of the launch team and their duties at Vandenberg and then summarized the scheduling immediately after launch. The discussion turned to final steps before shipping.

Peterson noted an unexpected problem that he termed "white gunk." This was a haze-like substance that had appeared on the Teflon insulating surface of the spacecraft following its thermal vacuum tests. Chemists from

APL's Research Center were now being enlisted to analyze the composition of the haze to determine whether it would contaminate the mirror of the AIRS experiment in space or create any other problem.

At the next meeting Peterson announced that the "white gunk" was deemed no problem. He then gave a quick briefing on Vandenberg decorum, with the reminder: "When you're out there, you represent the Lab." Certain strict rules prevailed at the Air Force base: seat belts to be fastened at all times, speed limits enforced, no alcohol (not even empty beer cans in a car trunk), car pass always displayed prominently, no cameras.

Friday, August 15, 1500: It was a hot afternoon with only occasional puffs of breeze. Polar BEAR returned in an APL truck from spin balance/mass properties tests at Goddard Space Flight Center, the large white cannister that encased it gleaming in the sun. As the APL truck backed into the loading bay of the Space Building, someone slid up the big garage door and began raising a hydraulic platform inside. One by one several team members assembled to lend a hand.

Nobody hurried, but everything clicked. First, the truck attendants handed down incidental paraphernalia—rigging cables, consoles, the four solar panels each in a long wooden case. A heavy red tool cabinet and a platform on wheels were ridden separately to ground level, as was the spacecraft package itself.

Of paramount concern was the cleanliness integrity of all equipment. After the unloading, someone lowered the outer door and raised an inner door on the opposite side, and the team moved everything into the multistoried high-bay area. Ray turned busy with a cloth and alcohol to remove dirt from all the outer surfaces, while Mueller rigged a vacuum hose to remove any remaining particles of dust and dirt. The two formed something like a car wash, through which Herbert and Carol Moran, in charge of packing and expediting, wheeled the gear piece by piece before continuing to the clean room entrance.

When the white-coated security guard inside the clean room raised the door, Bill Leidig, the chief payload mechanic, and Jim Jaquet (a Navy ensign on a temporary assignment with the APL Space Department), each wearing white staticproof coats, brought everything inside. Others went through a side passage to don white coats from a rack before entering the room through a door opened only by punch-key combination. The transfer completed, the guard lowered the door and secured it with a padlock to which he held the only key.

Leidig took charge of opening the canister. First, he pushed a valve that released pressurized nitrogen inside, then loosened the top bolt by bolt. Others adjusted a strap and positioned an overhead crane to lift it. Slowly the heavy top rose, showing first the gleam of Polar BEAR's silver Teflon thermal reflective coating.

After quick inspections to confirm the OK condition of at least the visible parts, the team transferred Polar BEAR to a smaller adjacent laboratory and locked the door. A summer weekend was about to begin. There was some easy joking. The last person out nodded to the guard.

Tuesday, August 19, 0900: In a meeting room at the Space Building, those responsible for various aspects of the Polar BEAR project gathered to rehearse their formal readiness review deliveries to the sponsors a week hence. The atmosphere among some 25 attendees was relaxed, occasionally jocular, always businesslike, and characterized by optimism.

The presentations included a ground station compatability review by Wade Radford, attitude system lead engineer. Among other reports were those on mass properties/spin tests by David Persons, launch vehicle interface engineer; on alignment measurements and reverification by Albert Sadilek, attitude alignments engineer; on vibration tests by Howard Wong, mechanical stress engineer; on antenna and solar panel deployment by Ted Mueller; on boom deployment by Jim Smola, attitude engineer; on electromagnetic compatibility by George Seylar, EMC engineer; and on magnetics testing by Chuck Williams, attitude engineer.

Tuesday, August 26, 0900: The readiness review took place in a more formal atmosphere, with representatives of the Defense Nuclear Agency and the Air Force listening closely and making notes.

Grant reported that during the past week the Beacon Experiment had developed a problem that required shipment back to the manufacturer, SRI International, in California. The correction necessitated no design change. The Beacon Experiment was now back at APL, after having undergone a new thermal vacuum test at SRI International. Grant explained that the morning's presentations would be rearranged so that Wong and Mueller could talk first and then leave to conduct a new vibration test on the Beacon. He added that the malfunction would not affect the shipping date to Vandenberg.

Some of the sponsors asked pointed questions, particularly about the thermal vacuum tests and about the Beacon malfunction. However, by consensus at the end of the day, the Polar BEAR spacecraft was deemed ready to fly.

Another major review occurred the following week in California. On September 4, a high-level presentation in Los Angeles to Lieutenant General Forrest McCartney, then head of the Air Force Space Division, confirmed the readiness of the mission to proceed toward launch.

Tuesday, September 9: The men from the machine shops who had custom tooled several parts of the satellite piece by piece were invited to have a final look. They went through the white-coat procedure, perhaps uneasy with the stringent cleanliness requirements. Polar BEAR, intact and ready to travel, stood mounted in state. The solar panels were missing (each packed in a separate box), and the experiments were covered in a black-coated thermal insulation. Red tags on some connections and shields indicated that these parts had to be removed before launch. Otherwise, the spacecraft appeared exactly as it would on launch day.

There is something awesome about an object soon to travel in space, away forevermore from human touch. Most of the men's precision work now lay buried within the exotic, strangely beautiful package. They circled respectfully, as they might a piece of modern sculpture, most of them instinctively with arms folded or behind their backs to avoid a hand in the wrong place.

Peterson thanked Charlie Burke, Marty Malarkey, and Phil Esposito in particular on behalf of the entire spacecraft team, and all of them "for the dedication you've shown. When we pushed on you, you responded."

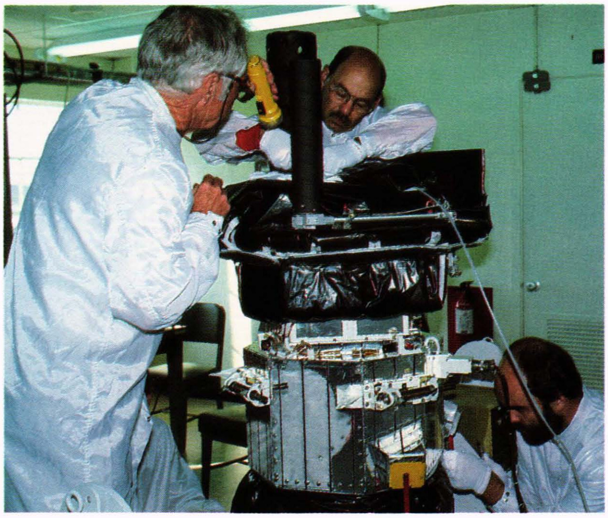
VANDENBERG AIR FORCE BASE

Friday, September 12: Polar BEAR made the cross-country trip without damage, flying aboard a C-141 from Andrews Air Force Base in Washington, D.C., to Vandenberg, and then moving by truck to the assigned building on the base. Several individuals and teams were waiting. Dodd, who coordinated the move, had arrived several days before to finalize liaison with Air Force personnel. The expeditor-packers under Moran had already set up consoles and other monitoring equipment shipped from APL. The mechanics under Mueller's direction wheeled the canister inside and opened it, then mounted the spacecraft for testing. Payload engineers led by Ray activated the batteries and air conditioning ducts and connected the individual experiments to their test consoles. Other personnel to arrive on the scene within the first few days included Wong and Persons to interface the spacecraft with the rocket booster, Brantley, as reliability engineer, and the lead engineers of the individual systems and experiments—Ogorzalek (AIRS) of APL, Mike Cousins (Beacon) of SRI International, and Leonard Scheer (magnetometer) of APL. Waiting to meet them were the Air Force project managers, Lieutenants Richard Roberts and Clarence ("Willie") Wilcox of the Air Force Space Division.

The Polar BEAR ground station (through launch), where field tests would occur, was a building on the base bearing the number 596, located on a low hill between the Pacific Ocean and the Scout launch pad. Enhancing the isolation, nothing but wiry desert plants covered the terrain. Snakes were said to reside in the brush. High barbed wire surrounded the building, and a clockaround military guard required identification of all people entering. (Entry to the base itself also was checked, of course.) The building consisted of several office and work areas, as well as a large room that could be isolated for a clean room. Besides people working directly on the spacecraft and its systems, the building also served as headquarters for the contractor and Air Force personnel connected with the launch.

PRELAUNCH SYSTEMS CHECKS

Vandenberg, Monday, September 15: Checkouts began on the electronic systems of Polar BEAR. The clean room was arranged with consoles against two walls, a table in the center, and the spacecraft at the far end. Varicolored wires and cables connected the spacecraft to the consoles, where most of the attention focused. Under Brantley's watchful eye, anyone entering an adjacent work area needed first to walk over sticky paper and pass their shoes through a set of rolling brushes to remove outside dust. The clean room itself required wearing a white static-free coat snapped at the wrists and all the way up the front.



Final inspection at the Vandenberg ground station before shipping Polar BEAR to the spin test. Bill Ray holds the light as Dorsey Reaser makes a white-glove adjustment and Doug Mehoke (below) attaches part of the black thermal blanketing.

Ray conducted the checkout procedures with Edward Reynolds, assistant payload engineer, and with Anna Fones, the payload electrical technician. Others entered and left as the schedule reached their responsibilities.

One test required activating the momentum wheel that would provide yaw control to the spacecraft. (A gravity-gradient boom would stabilize roll and pitch.) The procedure, which involved revving the wheel to its maximum speed and timing its deceleration, was conducted by Baxter Philips and Scheer.

By midday, what with the technical housekeeping and a general interest in the procedure, the traffic in and out of the clean room began to get heavy, and Ray locked the door. When people jiggled the handle, he waved them away unless they clearly needed to enter. "We get hostile around here," said Reynolds in passing. Nobody appeared upset, just busy. Printers drummed out data sheets that the team members covered with notations. Any conversation followed the terms of the procedure: "My Y and Z are saturated... Two point five negative... Minus three point one one volts."

POLAR BEAR AND VANDENBERG ROUTINES

Since the multiple batteries of the spacecraft received charges in a constant "trickle," someone needed to monitor the vital signs day and night. Barbara Wyatt, secretary to the launch team, posted a chart that divided the off-work time into daily 4-hour segments. Virtually all hands signed to take turns, including Wyatt.

Anyone visiting the pad or spin test facilities—areas of inherent danger—was required to carry an orange badge, received only after attending a safety lecture. The badge, identified by a number, was left with the guard at the gate by anyone entering the areas and retrieved upon leaving. This provided a continuing record of people in the two facilities.

The safety lecture, delivered by Donald Forney of NASA, covered several special requirements, along with a review of standard warning signals and safety procedures. For example, while a crew often works long hours before a launch, Range Safety limits time at the pad or spin test to 12 hours—14 the absolute maximum—to prevent fatigue leading to dangerous mistakes.

Among specific safety rules, no spark-producing equipment could come within 10 ft of a solid rocket motor (e.g., the fourth stage of the Scout rocket to which the Polar BEAR spacecraft was attached during spin tests). Anyone working in the vicinity of the rocket was required to wear a static-dissipative coat and a leg grounding device. The required leg stat consisted of a rubber strap fastened around one shoe, wired to another rubber strap placed around the leg. At the spin test facility, no more than 15 people could be in the chamber during preparations. During actual spin, with the chamber cleared, no more than 9 people could occupy the adjacent support room, while a maximum of 25 were allowed in the entire compound.

At the start of each work day, the heads of the teams representing the payload, the launch vehicle, NASA, and the Air Force met to keep each other posted. The key participants sat around a square of long tables while others listened from nearby seats. Presiding was Forney, who supervised NASA safety requirements on the base.

At the other end of the day, usually at 1545, Peterson conducted a meeting in Building 596 of all spacecraft personnel. Everyone gathered informally, leaning against walls and perched on the table by the coffee urn. This closed the formal work day.

At Vandenberg AFB, the daily morning meeting of team heads representing the payload (APL), the launch vehicle (LTV), NASA, and the Air Force. Presiding is Donald Forney of NASA, lower right. Others around the table, R-L from Forney are William Ray, Robert Dodd, J. T. Mueller, and Max Peterson, all of APL. Seated behind Ray and Dodd is David Grant, Polar BEAR program manager. Members of the LTV team, not shown, are seated at a far table facing the others.

Tuesday, September 16, 0745: Carl Hale of Vought (LTV), head of the civilian team preparing the Scout rocket, noted at the morning manager's meeting that the Scout would arrive on the launch pad two days hence, as scheduled.

Peterson reported that spacecraft checkouts were also proceeding on schedule. After discussing other logistics, e.g., the possibility of needing a cherry picker on the launch site to remove the spacecraft's battery enabling plug in case of a scrub, the participants drove off in a dense, chilly fog for their various work points on the base.

Thursday, September 18: After the morning briefing, the participants heading to Scout/Polar BEAR facilities found themselves part of a snail-paced convoy as a flatbed truck drove the Scout vehicle to its pad. A rule of the base prohibits cars from passing a fueled rocket in transport. The convoy, moving at 5 mph, wound along the ocean road, affording those caught in it a prolonged vista of ocean and rocks. From a distance, the Scout resembled a long, white pen. Slowly, the truck left the main road (releasing cars that zoomed free like bees from a cage) and climbed the final hill on the spur road leading to the pad.

Over the next two hours, a crew, dwarfed by their huge charge—63 ft long even without its fourth stage and nearly 4 ft in diameter at its widest point—carefully chain-hoisted the fueled rocket from the truck bed onto a launching cradle. A long shed with attached work platforms moved smoothly on tracks to enclose it all.

Concurrently, at the 1545 briefing of spacecraft personnel that afternoon, Ray reported: "All Polar BEAR systems have been checked successfully. Blockhouse and adapter checkouts begin tomorrow."

MATING TO FOURTH STAGE AND SPIN TEST

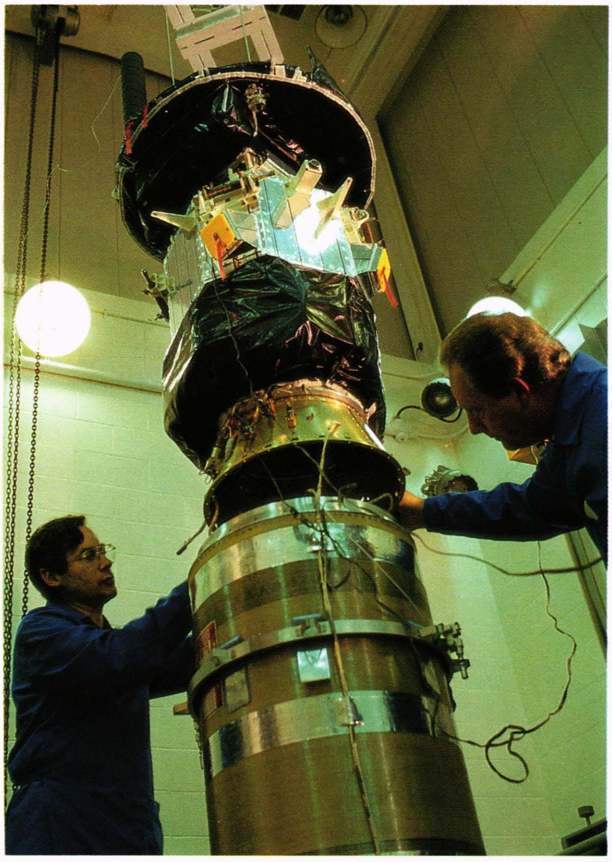
Wednesday, September 24: The spin building consisted of a small vestibule, a workshop, and the spin cham-

The Polar BEAR team holds its daily afternoon briefing at Vandenberg AFB in Building 596, which served as the satellite ground station. L-R: Max Peterson, Ted Mueller (in the doorway, Lieutenant Richard Roberts and Master Sergeant Keith Cochran of the Air Force, Don Forney of NASA (profile), John Meyer, Anna Fones), Ed Reynolds, Ryan Henline, Dick Brantley, Navy Ensign Jim Jaquet, and Bill Ray.

ber. At spin test, Polar BEAR would be mounted to the Scout's fourth stage and the total unit rotated at the high spin it would reach during launch to ensure the same perfect balance achieved in the earlier spin test of the payload alone at NASA/Goddard. Even a slight imbalance could place the spacecraft on a lopsided course.

The Scout's fourth stage, weighing 662 lb, had already been mounted on the spin pedestal. Since the rocket now contained its load of solid fuel, the explosive potential in the chamber dictated steady, deliberate care, even for uncovering the spacecraft several yards away. After being weighed (the scale registered 216.1 lb), the spacecraft continued by hoist to a hovering position over the fourth stage. The team worked from hydraulically operated platforms capable of moving vertically alongside the 12-ft face of the combined units. Payload personnel mated the two units using an adapter designed to spring apart (with a small explosive bolt triggered on command) at the time of separation in flight.

The final preparation involved building up the complete satellite to be launched by adding the solar panels and such ancillary parts (each weighed separately) as despin cables and weights, rocket straps, sublimination timer, and antennas. When Leidig modified one of the plugs, he weighed the old one and the new one, then recorded the adjusted total weight. The payload ultimately weighed 258.8 lb.



The Vandenberg AFB spin test facility. An overhead crane carefully lowers the Polar BEAR with its flange-like adapter onto the solid fuel Scout fourth stage, guided by Ted Mueller and Bill Leidig. The 12-ft-high combined unit remained mated throughout spin test and launch, separating only in orbit when the adapter sprang apart with a small explosive bolt triggered on command.

Attaching the 5½-ft solar panels was the special charge of John H. Meyer, payload systems technician, who had recently checked their electrical properties. A separate padded, wooden "coffin" housed each panel. Meyer, wearing white gloves to ensure against finger smudges, lifted out each with care, bore it across the floor like a chalice of thin crystal as everyone fell involuntarily silent, and handed up one end for the others to bolt in place.

Thursday, September 25, morning meeting: Peterson reported that everything was "A-1 with Polar BEAR," and she was ready to spin. Hale from LTV reported on schedule with the Scout, ready to proceed with ordnance installation. Hale: "It's going so smooth, it's scary."

When the time came for the spin, base personnel cleared the chamber and performed the potentially dangerous operation by remote control. Only those essential to monitor the equipment remained in the vicinity.

LAUNCHER MALFUNCTION DELAYS REHEARSAL

Friday, October 3: After completion of the spin test, the mated spacecraft and fourth stage moved to the launch pad for attachment to the Scout rocket. The total package on the pad now stretched 75 ft from thruster fin to nose cone tip.

In one of the checkout procedures, LTV discovered a defective bearing in the gantry used to raise the Scout from a horizontal to a vertical position for launching. After consultations, the launch managers placed a hold on the projected October 8 launch date, pending a complete assessment of the problem.

Monday, October 6: A closed-door conference between LTV, NASA, and the Air Force replaced the usual open briefing at 0745.

Next morning an LTV expert flown from Texas, having worked all night, identified the problem and found a solution, which cleared the way for a revised schedule. The dress rehearsal was set for the next day, the 8th (original launch date), and the launch for October 10.

LAUNCH REHEARSAL

A dress rehearsal is as important to a launch as to a play. It is the time before final commitment to pace through all the details in real time, both to make the participants comfortable with the operation and to expose any problems that might not have been apparent before pacing out full sequence.

A countdown follows a progression of interdependent steps laid out during design and development. For Polar BEAR, there were separate procedures for the launch vehicle and for the spacecraft, so that the two moved independently while connecting at various points. Scout rocket control was centered in the blockhouse, located a safe distance from the launch pad but in direct contact with the pad at all levels of operation. Building 596, one-fifth of a mile from the pad, served as the spacecraft control center and ground station. Several miles away on another part of the base stood Building 7000, headquarters of the heavily secured Western Space and Missile Center, which served as the Launch Operations Control Center. Here, mission directors and their aides monitored all circuits and stood ready to make any ultimate decisions.

Wednesday, October 8, 0730: While the spacecraft team in Building 596 began routine communications checks, Mueller, Reynolds, Brantley, and payload technician Dorsey Reaser drove to the pad, where Polar BEAR was now mated to the Scout rocket, to perform two functions that on launch day would be the final hands-on procedure. First, reaching through an access door in the nose cone shield that now covered the spacecraft, they installed an ordnance arm connector. This completed the circuitry for firing the adapter ring connecting the spacecraft and fourth stage at the time of separation. (It was necessary to do this even in dress rehearsal in order to monitor the telemetry involved.)

They positioned a portable antenna to transmit satellite housekeeping and experiment signals to the Building 596 ground station. Finally, they inserted the battery enabling plug, which connected the spacecraft systems to the direct power of the onboard batteries. (In space, the satellite's solar panels would recharge the batteries.)

Simultaneously, the Scout vehicle crew worked around the long rocket. Engineers with headphones stood by an access door in the second stage, testing telemetry and relaying the results to the blockhouse, while mechanics prepared the cradle that would raise the vehicle to a 90° vertical launch position. By now the vehicle countdown had begun, as evidenced by the voices from pad and blockhouse broadcast over a loudspeaker in the courtyard.

The Scout rocket countdown was divided into seven "tasks:" ground support systems activation, electronic systems checkout, reaction control systems fueling (launch countdown only), launcher securing and erection, ignition/destruct systems checks, countdown evaluation, and terminal countdown.

At the pad. Inside the mobile shelter, LTV engineers check out the 63-ft-long first three stages of the Scout rocket. The combined fourth stage and spacecraft will be mated at the open end.

Very slowly, so slowly that it was necessary to orient against one of the low mountains in the background to have any sense of movement, the 75-ft Scout rocket and payload began to rise from horizontal to vertical.

The rest of the dress rehearsal became routine, and by midafternoon all procedures had been completed. After the rocket moved back to a horizontal position, the shed slid back over the vehicle and spacecraft. Members of the spacecraft crew removed the battery enabling plug and reattached the umbilical, thus returning the on-board batteries to a trickle charge.

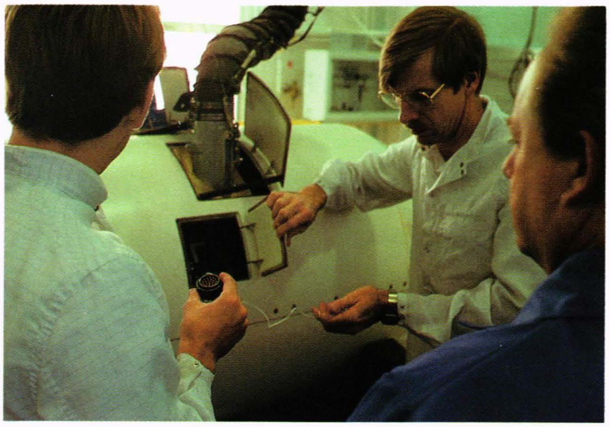
As is customary, one day separated rehearsal and launch to allow time to correct any problems that might have been detected.

SCOUT GYRO CAUSES SCRUB

Friday, October 10: At 0820 the spacecraft countdown began. At 0822 Reynolds and Mueller made what they thought was their final visit to the pad to install the battery enabling plug. At 0900 the vehicle countdown began. By 1000 the Polar BEAR team had completed verification of the signals from the Beacon Experiment while LTV had reached item 60 of its electronics system checkout. By 1100 the rocket countdown had entered the phase of guidance system checkouts. At item 94 of Task 2 concerning gyro torquing, the reporting voice from the pad paused longer than usual to give the check. It was approximately T minus 5 hours (T minus 285 minutes, to be exact) when a steady voice from the blockhouse declared: "The flight is scrubbed for today."

Those working the spacecraft might have hoped, for a few seconds at least, that the announcement was a mistake and would be retracted, but everyone knew that the blockhouse transmitted no frivolous statements during countdown. In Building 596 the spacecraft turn-off commands began. By 1122 Ray had declared: "All systems down."

The Scout rocket had six gyros, one each for rate and displacement of the pitch, yaw, and roll axes. The roll



At the pad, Vandenberg AFB. The satellite team conducts its final hands-on procedure, installing the battery-enabling plug on Polar BEAR (now hidden) through an access door in the launch vehicle heat shield. L-R: Ed Reynolds (holding the plug), Dick Brantley, and Bill Leidig. Note the attached safety lanyard allowing retrieval if the plug is accidentally dropped.

displacement gyro had not registered the drift necessary to prove that it was functioning properly. According to Paul Goozh, the NASA Scout program manager: "It might only have been a particle of contamination that hung up the gyro, but it could have been more serious. We felt we couldn't take the chance." The same failure during launch could have led to a deviation in the final orbit of the satellite and might have required the range safety team to destroy the launch vehicle and payload. (A postmortem of the gyro conducted by NASA confirmed the decision. A gyro bearing had cracked and could well have resulted in mission failure.)

Experienced launch teams have minimized losses and rescheduled before. That evening, at the motel where most of the payload team was staying, both Grant and Peterson explained what they had been told of the problem and the options. The failure had not been the fault of the spacecraft (as a local newspaper mistakenly reported). However, it was an immense letdown for the Polar BEAR team, after building psychologically for weeks toward launch day. The gyro would have to be replaced. The time lost to ship and install it meant that the launch could no longer take place within the October window. The next day most of the Polar BEAR team headed home, while shippers Moran and Eddie Lapp returned to storage the crates they had assembled for quick packing.

Dodd and Reaser stayed behind in the role of caretakers. A launch rescheduled within six weeks would allow the spacecraft to remain mated to the fourth stage, avoiding a second spin balance. The combined unit was moved to a separate storage facility. With the batteries discharged all the way and then shorted out, Polar BEAR went into hibernation.

LONG HOLD ON FINAL CHECKOUT

Tuesday, November 11: A month later, the Polar BEAR team reassembled at Vandenberg and immediately began to function as before. Normal base operations were closed for Veterans Day, but the dress rehearsal proceeded. By 1400, the rocket countdown had reached T minus 4 minutes of Task 7: Terminal Countdown. The entire spacecraft assembly stood erect at the pad, technically 4 min before liftoff.

At this point, a hold is usually projected to allow time for vehicle alignment—the procedure to find the exact mechanical setting that will raise the vehicle to its precise launch angle. The hold continued as the sun set, and floodlights took over to pick out the rocket as the only object visible against a black sky. In recent years, during the ascendancy of the Shuttle, Scout rockets had been shelved and considered relics of the past—this despite their record of 79 successes out of 82 launches. In the interim, the launcher had been fitted with a new mechanism whose behavior in the field turned out to be different than expected.

On the pad, as the night air grew chilly, technicians and mechanics in blue coats and hard hats moved purposefully under the huge floodlit rocket, while in the office engineers diagrammed the problem on a blackboard.

Meanwhile the battery temperature in the spacecraft had begun to rise, and Ray's team watched the readings with growing concern while minimizing power loads where they could on nonhousekeeping systems. By 1900 the Scout people had solved the alignment problem, and at last they were able to lower the vehicle from its 90° position. A voice over the speaker announced the diminishing angles. At 5° the motion slowed, and at the 1° angle it stopped, to leave the vehicle suspended lightly over its cradle.

Reaser, of the spacecraft team, climbed the cradle scaffolding, opened an access door on the nose cone, and disconnected the battery enabling plug to stop the drain on the spacecraft batteries. He replaced the enabling plug with a dummy one.

Accompanied by the warning horn, the long shed slid on its tracks to cover the vehicle, and, with no further danger of jarring, the launcher crew lowered it the final degree into the cradle. After the spacecraft crew had reconnected the umbilical to resume trickle charging, they closed operations for the night except for the battery watch.

SUNNY LAUNCH DAY

Thursday, November 13: By 0800 the countdown had begun for both rocket and spacecraft. The Polar BEAR spacecraft, covered by the Scout nose cone, could be reached only through a 3-in-square access door. Reynolds opened it, shone down a flashlight, and then by sense of feel installed the battery enabling plug.

In the blockhouse, LTV engineers manned each console in the rows facing the TV monitors. Although the blockhouse was the command station for the rocket, it also was the post for two members of the spacecraft team. Peterson followed the simultaneous countdown procedures to ensure coordination between rocket and spacecraft. Meyer monitored battery readings via the

The blockhouse during the countdown. Max Peterson and John Meyer of APL join LTV engineers at the consoles. Peterson ensures that spacecraft countdown procedures are coordinated with those of the rocket. Meyer monitors the charge on the spacecraft's eight batteries. The charge will continue via an umbilical cord until the cord is pulled mechanically four minutes before liftoff.

umbilical cord that would be attached to the spacecraft until it was pulled mechanically 4 min before liftoff to maintain an even charge on Polar BEAR's eight batteries.

Miles away at the center of the base in building 7000, Grant and Dodd sat at individual TV monitors along with other key personnel from NASA, the Defense Nuclear Agency, the Air Force, and LTV. The monitors provided live coverage of final preparations on the pad, both outside and inside the rocket shed. Another screen carried weather satellite pictures. Visitors invited to monitor the launch included George Weiffenbach, satellite pioneer and former head of the APL Space Department, and Vincent Pisacane, the current department head.

In Building 596, Ray's payload team continued its systems countdown. The day was warm and sunny, and when people could take a break they strolled outside. At approximately 1200, the base safety officer cleared the area of all but assigned personnel. By now, military security police had blocked roads on the perimeter of the launch area.

At 1500 buses took about 300 invited spectators up a winding road through the back of the base to a hill overlooking the launch site several miles away. Despite the bright morning, a haze had begun to cover the hills, a haze heavy enough to make the distant ocean indistinguishable from the sky. A chilly wind began to blow. Two sets of TV commentators huddled in improvised windbreaks as they spoke into microphones held in front of them. "T minus four minutes and counting," announced a voice over a speaker attached to a small support building.

1623. All at once the numbers were coming in reverse order in the classic countdown pattern: "Ten, nine, eight ... one... liftoff!" After the years of preparation, it was hard to believe. The rocket rose to view between two hills, leaving behind it a blast of fire that turned to smoke and remained in the air like a snaking white line drawn on a slate. Inside Building 596, the payload crew (required to remain under cover) heard the roar of liftoff loudly enough to feel the power being released. On the spectator hill, it took several seconds to hear the same sound. A minute later the launcher and spacecraft had disappeared into the haze, leaving only a twisted smoke trail that began to dissipate.

"Third stage burnout," continued the voice on the loudspeaker. "Waiting for step ten. Still have a good signal....Bit of roll. Motors are correcting...."

"...Exciting to see an old timer get a new lease on life," chattered one of the TV newscasters into his microphone.

1700 in Building 596. The launch trail had barely cleared before Carol Moran and Eddie Lapp were moving equipment into open crates lined up at the ready. Within 2 hours, the first shipment back to APL was being loaded into a waiting truck where the consoles involved would, six days hence, be used to activate the experiments aboard the spacecraft.

1800 in Building 596. The spacecraft team and sponsors crowded around Paul Lasewicz of the Navy Astronautics Group who had telephone and data communications with the Group's tracking station in Hawaii. First, he announced that fourth-stage separation had taken place. Next, from Ted Mueller who had been examining the printout: "Solar panels are out and separating, and we've got *goood* temperature!" There was general ebullience.

General ebullience from the Polar BEAR team greets the news that the solar panels are out and separating in orbit. Paul Lasewicz of the Naval Astronautics Group (on the phone) relays the information from the Group's station in Hawaii 90 minutes after launch. L-R: (foreground) Vince Pisacane, Dave Grant, Bill Ray, George Seylar, and Air Force Lieutenant Willie Wilcox.

In orderly fashion over the next three days, the Satellite Tracking Facility at APL in Howard County, Md., began to stabilize the satellite under the direction of Radford, who served as manager of postlaunch operations. The station activated the momentum wheel for successful yaw stabilization, deployed antennas, and extended the gravity-gradient boom. (Then, during the first month of flight, all the spacecraft functions were verified, beginning with magnetic capture.) The initial orbital parameter tracking data, processed at APL, were provided by the North American Air Defense ground station in Sondre Stromfjord, Greenland.

Wednesday, November 19, 1500: Six days after launch, as Polar BEAR passed overhead, program managers assembled at the APL tracking station to make their initial contacts with the on-board experiments. Station personnel worked the long banks of controls in the room facing the "big dish" antenna outside, while in an adjacent room the scientists and sponsors huddled over several sets of consoles.

1520. Ogorzalek began typing the computer commands that would activate the AIRS experiment.

Transmissions from Beacon appeared encouraging. The other experiment, the magnetometer, had been activated the day after launch because it provided part of the spacecraft stabilization and had already proven to be functioning to the satisfaction of principal project scientists Bythrow and Zanetti.

1615. Transmissions also were being received in another part of APL at the AMPTE Science Data Center, which had been set up specifically to process data from the AMPTE magnetospheric particle satellite launched in August 1984 (see the *Johns Hopkins APL Technical Digest,* Vol. 5, No. 4 (October–November 1984) and the article by McEntire elsewhere in this issue). There, the data were translated on console screens into color images.

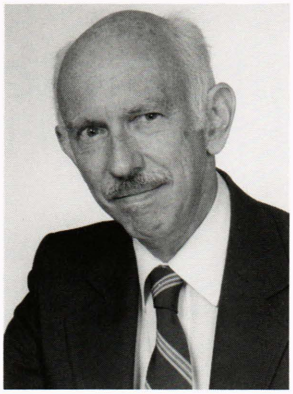
The data personnel, working their keyboards with something like the passion of the chase, isolated signals that made increasingly cleaner color images. "Ohh, good interpolation, the structure is certainly there," muttered someone appreciatively as a rainbow picture of an aurora took shape on the screen.

OVER AND OUT

Thursday, December 11: The Polar BEAR spacecraft team and its sponsors met at APL for the formal transfer of the spacecraft (i.e., its transmissions) to the Navy Astronautics Group, which would henceforth be responsible for operational tracking, maintenance, and control. During the month of tracking at APL, there had been a normal share of problems. For example, thermal engineer Mehoke reported that the batteries were running hotter than expected. He said that a discussion among the payload engineers over whether the higher temperature would shorten Polar BEAR's battery life had resulted in a consensus that the batteries were in no danger of failure. (The Oscar-13 satellite had been running at higher temperatures than originally expected for 20 years.) No operational changes were being proposed.

General handshaking followed.

THE AUTHOR



WILLIAM McCLOSKEY was born in Baltimore and received his B.S. degree from Columbia University in 1951. After serving as a line officer with the U.S. Coast Guard, principally aboard a cutter based in Alaska, he worked for the *Baltimore Sun* newspaper, the U.S. Information Agency in Madras, and in industrial public relations. He joined APL's External Relations Group in 1962. His responsibilities include federal liaison in Washington.

As a freelance writer/photographer, he has become increasingly identified with maritime issues, and his articles on these subjects have appeared in numerous publications including *Smithsonian*, *Atlantic*, *New York Times Magazine*, *Oceans, International Wildlife,* and *National Fisherman.*

Mr. McCloskey's most recent novel, *Highliners* (McGraw-Hill, 1979), grew from his experiences working during leaves and vacations as a commercial fisherman in Alaska. He is currently writing a book for Paragon House about inshore commercial fishermen on the North Atlantic coasts of Europe and North America. He has written several articles for the *Technical Digest*, including ones on APL duty with the Navy's surface fleet, innovations in fishing boat technologies, the Programmable Implantable Medication System, the Chesapeake Bay, and Project AMPTE.