THE SMALL ASTRONOMY SATELLITE-3

A General Description

by
H. B. Riblet

The SAS-3 X-ray Satellite Program started in 1971 and entered its last phase with satellite launch in May 1975. Both the control and experiment units continue near-flawless performance. Program objectives, components, and subsystems operations are briefly described.

Introduction

The SAS-3 spacecraft shown in Figs. 1 and 2 has two basic units: the control and the experiment sections. The latter can be designed for various astronomy missions including X-ray and gamma-ray research. The SAS-1 and -2 experiments used an X-ray and a gamma-ray telescope, respectively. SAS-3 used several independent and more extensive X-ray detectors. The experiment section simply bolts onto a mechanical interface structure that is a part of the control section and can be designed to match the mounting requirements of any experiment. The control section includes all support systems such as power and thermal control, attitude control, command, and telemetry. The experiment section of SAS-3 was designed and fabricated by the Center for Space Research of the Massachusetts Institute of Technology (M.I.T.). The control section was designed and fabricated by the Applied Physics Laboratory of The Johns Hopkins University (APL/JHU).

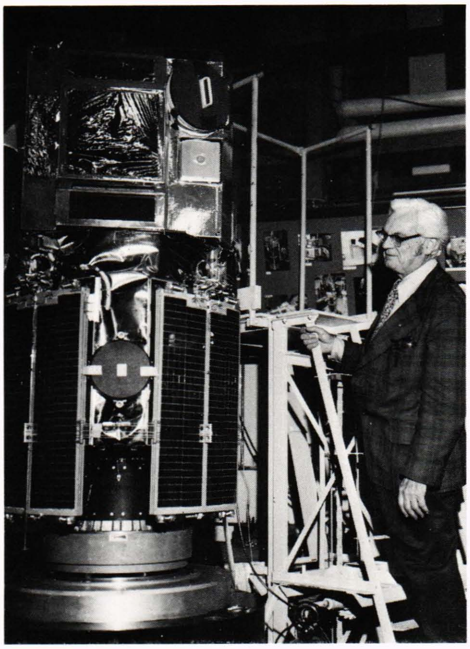

Fig. 1—SAS-3 spacecraft, with folded solar panels and thermal blankets exposed (being inspected by H. B. Riblet prior to vibration testing).

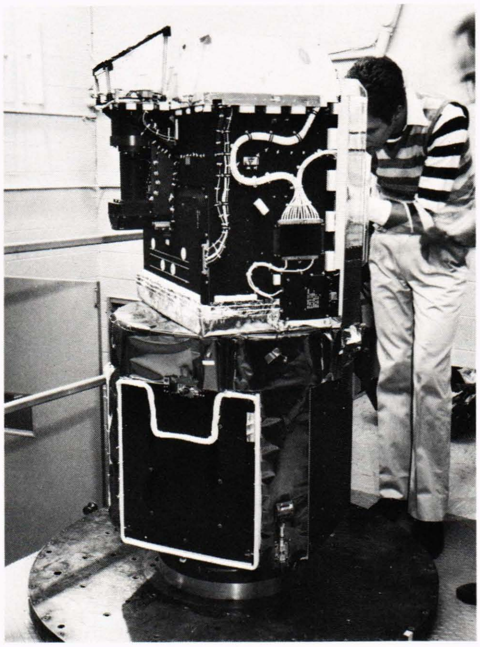

Fig. 2—SAS-3 spacecraft in the spin facility. (The space radiator can be seen in the absence of solar panels. The experiment's thermal blanket has also been removed.)

Mission Objectives

The overall objective of the SAS-3 (Explorer 53) experiment is to investigate in detail those areas of X-ray astronomy that are essential to understanding the physical processes involved in

---

The Small Astronomy Satellite Program is sponsored by the National Aeronautics and Space Administration and is managed by the Project Office at the Goddard Space Flight Center.

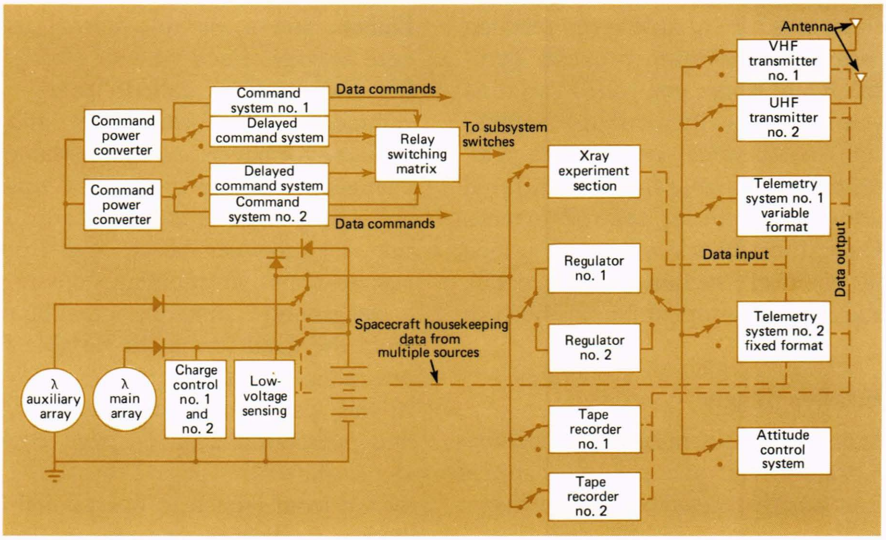

Fig. 3—Simplified block diagram of the spacecraft systems.

the generation of X rays by celestial bodies. The experiment uses state-of-the-art techniques to increase the knowledge of X-ray astronomy beyond that which has been obtained by sounding rockets, balloons, and previous satellites.

The X-ray astronomy parameters being investigated include the location of X-ray sources to 15 arc-seconds, the existence and identification of very weak extragalactic sources, the properties of transient X-ray phenomena associated with novas and supernovas, the absorption of the low-energy diffuse X-ray background by interstellar matter, the long- and short-term variations of the X-ray source Scorpius X-1, the detailed energy spectrum of X-ray sources and background from 0.10 to 50 keV, and the periodic time variations of X-ray sources (e.g., X-ray pulsars) with periods from 10^{-3} to 10^{3} s.

Control System Description

A simplified block diagram of the spacecraft systems is shown in Fig. 3. The power system shows the main and auxiliary solar array, the charge control system, and the low-voltage sensor. The battery is disconnected from the main bus when the voltage goes below 13.2 V but is trickle charged from the auxiliary array.

The command system is connected to both the battery and the main solar array and cannot be switched off. The X-ray experiment and tape recorders are connected to the main battery bus and have their own voltage regulation.

The telemetry system and attitude control subsystem are operated from redundant voltage regulators whose output is 13.5 V ±2%. Each subsystem, which will be described in detail, can be switched off in case troubleshooting is required.

Attitude Control System

The attitude control system consists of three basic subsystems: magnetic control and bias, reaction wheel stabilization and gyro control, and passive nutation damper.

The magnetic control system uses three mutually orthogonal electromagnetic coils parallel to the X, Y, and Z axes of the satellite. Magnetic dipoles of varying strengths are generated by controlled currents in these coils. The Z coil, which is collinear with the axis of asymmetry, is used to provide a dipole moment that reacts with the earth's magnetic field to torque the spin (Z) axis of the satellite to predetermined positions. The X and Y coils have two functions: (a) to use the outputs of the X and Y magnetometers in the proper phase relationship to generate coil currents that create torques about the spin axis by reacting with the earth's magnetic field; and (b) in combination with the Z coil to compensate for any residual spacecraft magnetization by using a steady coil current controlled by ground command. The latter use is the function of the magnetic trim bias system.

The reaction wheel stabilization and gyro control system, the heart of the SAS-3 spacecraft, uses new concepts and modes of attitude control. The basic control element is the variable speed reaction wheel whose angular momentum provides gyroscopic stabilization and whose controlled variation of speed gives azimuthal position control. Sources of control signal for the wheel are the rate gyro, the star camera, the pitch signal from the infrared (IR) scanner, and a tachometer control for constant speed. These four modes will be described in the "Attitude Control" section in some detail, for it is in this area that the operation has been so spectacular.

Attitude Detection System

The attitude detection system of SAS-3 includes three types of transducers: star position cameras and sensors, sun position detectors, and a vector magnetometer.

There are two star cameras, one looking in the direction of the spin (Z) axis, the other looking orthogonally along the Y axis. When locked onto a star, they track its position until it is out of view. The cameras then lock onto a new star, which they track similarly. During the tracking mode, coordinates of the star's position are telemetered. The positions can later be related by a star map to determine the orientation of the X-ray boresight. The accuracy of the star-tracking cameras is about 10 arc-seconds. An auxiliary star sensor, also looking along the Y axis, is provided as a backup. It is not a tracking instrument but a sensor that detects star-generated output pulses traversing an N-shaped reticle. The time spacing of the pulses depends on the elevation angle of the reticle. By examining the time relationship of the three pulses and the crossing time, star positions can be determined to about 3 arc-minutes.

There are also two types of sun sensors, one that depends on a spin scan past the sun, and another that reads sun position without a scan. Each has a resolution of about 0.5°.

The vector magnetometer is a standard instrument used in most spacecraft for measuring the earth's magnetic field, from which some satellite position information can be determined.

Telemetry System

The telemetry system is basically a standard pulse-code modulation (PCM) digital readout that phase-modulates a VHF transmitter. The telemetry has two modes of operation: a fixed format that was established and programmed into a programmable read only memory (PROM) before launch, and a variable format using read/write core storage. Each type of storage is partitioned into two sections called "pages" that include a redundant fixed-format page and two separate variable-format pages. The variable format can be changed from the ground by uploading specific software programs into the core storage. In addition, bit rates can be changed from 125 bits per second (bps) in doubling steps to 16,000 bps.

By ground command, operation can be switched from the fixed format to variable format or from one page to another. Using the variable format in this way, launch data are located on page 1 and operational data on page 2. After launch, a single shift from page 1 to page 2 enabled us to switch from launch to operational data. The data stream is divided into major frames containing 256 minor frames, with 816 bits in each minor frame. An ultrastable crystal-controlled oscillator is used to generate the clock for the telemetry system, as well as for other frequency-dependent systems. The oscillator has a frequency stability of 1 part in 10^{10}/h under normal satellite operating temperatures. Thus all the timing and control functions of the satellite have a common stable-frequency source. The telemetry system has additional important features such as three 64-channel analog commutators and two 16-channel digital commutators, an analog-to-digital converter, error-detection coding, and two tape recorders for the storage of 6×10^6 bits of data.

Command System

The SAS-3 command system used the standard NASA 64-bit frequency shift keying (FSK) word amplitude-modulated 50% by a sine-wave bit-synchronizing signal. The system consists of redundant components connected so that either of two redundant Delayed Command Subsystems (DCS's) can be used by proper coding of the command word rather than by switching system connections. Antennas, receivers, bit detectors, decoder logics, and relay coil matrix are all redundant, but not the relay contacts. The system provides 56 ON or OFF relay commands and any number of data commands; 24 bits of the data command word are used for coding. Redundant delayed-command storage is also provided. Up to 15 commands of any combination can be stored in each redundant system, giving a total of up to 30 delayed commands if desired. Delays between 3 s and 2.4 h can be achieved with a minimum separation of about 2 s. The resolution time of execution of the first command is about 0.5 ms. A program of delayed commands can be stored for continued reuse since they are not destroyed when used but are recycled into storage. It is unnecessary to use all of the 15 commands available in either of the storage systems; zero bits can be inserted to fill unused words so as to occupy the storage completely, thus recycling all bits to their original positions.

The DCS is of special importance in operating the SAS-3 attitude control system. It allows changes in attitude, such as spin-axis precession, and spin-rate changes to be performed at any time in the orbit rather than only when in radio contact with the control station. It will also, for example, turn on heaters and other housekeeping systems at certain times in the orbit, such as at the beginning or the end of a sunlit period.

Power System

The SAS-3 power system includes the solar collector array, a nickel-cadmium battery, and a charge control system. The solar array provides a minimum of 63 W of orbit average power. The battery has a nominal capacity of 8 ampere hours.

The charge control system uses a digital coulometer that meters the Amin discharge and charge. It is adjusted so that when 110% or 125% (as selected by ground control) of the discharge power has been returned during the charge cycle, the array current no longer needed for battery charging is shunted by transistor power switches to reduce the voltage on selected sections of the array. Array current is allowed to continue to the battery at a trickle charge rate. The charge control circuits are redundant and can be chosen by command switching. A low-voltage sensing switch is used to remove the battery from the load line when the battery reaches 13.2 V. The nominal battery voltage is 16.1 V.

The solar array blades can be rotated by ground command to collect the sun's energy efficiently as the spacecraft attitude changes with respect to the sun. In this way a relatively constant array power is available at all attitudes. The rotation commands need not be executed frequently, since the aspect angles for good attitude are quite broad.

Thermal Control

An active thermal control system was used in SAS-3 in addition to passive thermal insulations. Thermal louvers were installed between heat-emitting elements (e.g., the battery and electronics books) and a thermal radiator. The louvers are similar to venetian blinds that open and close in response to the temperatures of the thermal sensors. When the louvers are open, heat is released through a low-resistance radiation path to the radiator. When they are closed, the radiation path resistance is increased and heat is conserved. Thus a relatively constant internal temperature is maintained with changing internal or external heat loads. Ground testing during thermal vacuum and in-orbit results show that the system is operating well and within the design specifications.

Launch Operations

SAS-3 was launched from the San Marco Equatorial Range off the coast of Kenya. The launching platform (San Marco) and the range control platform (Santa Rita) are located about 3 miles offshore in Formosa Bay, which is 18 miles north of the town of Malindi. The Range is operated by the Italian Government through Centro Ricerche Aerospaziali (CRA), the Italian Space Agency, which is administered by the University of Rome. The Scout launching vehicle was transported to Kenya via commercial shipping and unloaded at the launch platform. The spacecraft and associated test equipment were flown to Nairobi, Kenya, by commercial air cargo and trucked from there to the launching site. The spacecraft field crew consisted of about 20 people from the Applied Physics Laboratory, 6 NASA project representatives, and 10 representatives from M.I.T.'s Center for Space Research. The field operations lasted about four weeks and were accomplished without serious technical difficulties.

In-Orbit Operations

The SAS-3 satellite celebrated its first anniversary of operation on May 7, 1976. Since the launch, all systems have operated flawlessly, and the performance results described in "The SAS-3 X-Ray Observatory" section have been outstanding. The satellite has been operated by the NASA Space Control Center together with the STADN station at Quito, Equador. Personnel from the Applied Physics Laboratory are on call for consultation during any unusual operational problems. There have been no failures in any system, and the attitude control system has surpassed expectations.