ARYABHATA—EIGHT MONTHS OF LIFE IN ORBIT

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INTRODUCTION :

'Aryabhata' India's first artificial earth satellite, named after the celebrated Indian astronomer and mathematician of fifth century (Cajorie 1919), has completed eight months of satisfactory performance in orbit, thus fulfilling most of the planned mission goals.

Launched on April 19, 1975 at $13^h\ 28^m\ 54.^s9$ (IST) into a near circular orbit of 600 km at an inclination of 51° by a Soviet Rocket from a Cosmodrome in USSR, the 358 kg satellite has completed more than 3500 revolutions round the earth (period $\sim$ 96 mts) so far, spending in this process in excess of 6000 hours in the hostile environment of space. All through this period, the different technological systems in the satellite have been functioning according to the design expectations, providing useful data of relevance to the future Indian satellite programme. The satellite continues to send useful data and is expected to function for a considerable period of time in contrast to the original design goal of six months useful life.

PRIMARY MISSION GOALS :

The primary objectives of the Aryabhata mission are:

(*i*) to indigenously design and fabricate a spaceworthy system comprising of structure, power, thermal control, telemetry, telecommand, communication, stabilization and attitude sensors subsystems and evaluate their individual and integrated performance in orbit,

(*ii*) to conduct scientific experiments in the areas of X-ray astronomy, Solar neutrons and gamma rays and Aeronomy,

(*iii*) to evolve the methodology of conducting a series of complex control operations on the satellite in its orbital phase,

(*iv*) to establish the relevant infrastructure for the fabrication and qualification of sophisticated high reliability spacecraft systems, and

(*v*) to set up the necessary ground based receiving, transmitting and tracking systems.

Thus, Aryabhata is the forerunner to the more ambitious Indian space programmes of future involving experiments in space science and applications using satellites.

IN ORBIT PERFORMANCE OF ARYABHATA :

The performance of Aryabhata in orbit can be discussed broadly under three categories : (*a*) the performance of technological systems, (*b*) the information from scientific experiments and (*c*) the results of application experiments.

(*a*) Performance of the Onboard Technological Systems :—

As mentioned earlier, the onboard technological systems included the satellite structure, the power systems, the passive thermal control system, telemetry, telecommand and communication systems, stabilisation system and attitude sensors. Detailed analysis of the data obtained for the first six months has led to the general conclusion that the various design and fabrication procedures adopted by the Indian scientists for the satellite structure and the other onboard technological subsystems are sound and have resulted in a spacecraft capable of withstanding the launch and orbital phases of the mission. More explicitly the following conclusions have been derived in respect of the performance of different subsystems in the orbital phase.

The integrated power system in the satellite comprising of the Soviet supplied solar panels and chemical batteries as well as the Indian built power control, logic, conditioning and regulation systems have performed as per the design requirements. The minimum solar array voltage recorded was 40 volts and the minimum battery voltage was 24.5 volts, both in accordance with the predictions of calculations taking into account the orbital illumination conditions ranging between 63 percent and 100 percent sunlit period and the load profile of the power system. Out of the 14 regulator lines, 13 regulators continue to provide steady output at levels of ± 9 and ± 14 volt for powering the various subsystems. One regulator (+9V) however went out of order in the 41st orbit that resulted in the incapacitation of the three scientific experiments. Subsequent attempts to revive this regulator through the command link did not prove successful.

The passive thermal control system, based on the principle of Stephen-Boltzman law of heat radiation and involving the use of suitable paints with carefully controlled emissivity to absorptivity ratio has enabled the maintenance of the internal temperature of the satellite within 0 and 40°C, the safe operation limits for the electronics systems located inside. This temperature control has to be viewed against the fluctuations of +80°C to —50°C on the outside surface of the satellite as it moves from the sunward to the dark side of the earth. It is also interesting to note that the predictions on temperature variations resulting from the changes in the angle between the spin axis and the sun-satellite line are within ±2°C of the observed values.

The satellite is spin stabilized by spinning it around the axis of maximum moment of inertia. In the last eight months, the spin has decayed from 50 rpm to 10 rpm ; the rate of decay being much lower than the original conservative estimate. This has eanbled the conservation of the onboard gas thereby extending the useful life time of the satellite from the standpoint of spin stability. The precession cone angle of less than 1° has been achieved with the help of the onboard nutation damper. The spin rate as well as the attitude of the satellite in inertial space are determined with the data from a set of triaxial magnetometers and digital solar sensors. The attitude could be computed with an accuracy better than ± 1°.

The data on the performance of different onboard systems are telemetered to the ground through a PCM/FM/PM telemetry system at a carrier frequency of 137.44 MHz. The data obtained during periods when the satellite is not within the radiovisibility zone of either of the two ground stations i.e. SHAR and Moscow, are stored in an onboard tape recorder and are played back at 10 times the recording speed as the satellite passes over one of these ground stations. The performance of the telemetry downlink system is satisfactory and the received ground signal strength on an average has been more than -125 dbw. The observed bit error rates during both playback and real time modes are around 0.05 percent including the ground instrumentation errors.

The PDM/AM/AM command uplink at 148.25 MHz, consisting of a 1KW transmitter and an encoder on the ground and a receiver with the appropriate decoder onboard the satellite has functioned reliably during the last 8 months. More than 500 commands have been transmitted to the satellite successfully for executing various functions onboard such as spinning the satellite, switching ON-OFF of different systems, change over, to redundant systems, tape recorder replay etc. The onboard signal strength in worst case has been observed to be -86 dbm and in the best case about -70 dbm, both within the design limits.

(*b*) Information from Scientific Experiments :—

The X-ray astronomy and solar neutron and gamma ray experiments provided data of scientific interest during the first few days. The third scientific experiment for the measurement of ionospheric parameters did not function in orbit as the ±9V supply to the experiment did not reach the payload during the switch 'ON' of the total satellite immediately after injection.

Detailed analysis of the data from the X-ray experiment is presently underway. The scan path of the proportional counter telescope, designed for investigations of X-rays in the energy range 2.5–18.75 keV, included the X-ray source Cygnus X-1. The energy spectrum of this source could be evaluated from the four channel data of this telescope and is shown in Fig. 1. The interesting aspect of this information is that the source at the time of observation was about to undergo an upward transition in its intensity as revealed by the ANS and Ariel V satellite detectors (Heise et al. 1975; Holt et al. 1975). The spectral information obtained from Aryabhata observations on Cyg X-1 is perhaps the first reported information to this effect, as the spectrum after the transition is considerably softer (Sanford et al. 1975). Aryabhata data yield a power law dependence for the Cyg X-1 spectrum with an exponent value of ~ 0.7±0.2. In the energy interval of 2.5-13.8 keV, the estimated intensity of this source is 0.84±0.3 photons/cm^2/sec.

Cyg X-1 is one of the interesting and complex X-ray sources, which belongs to a binary system, where X-ray emission apparently takes place during the mass transfer from the OB supergiant onto a compact companion. This source is known to exhibit intensity variations with time scales of the order of milliseconds, minutes and even days (Boldt et al. 1974). Besides, flare-like enhancements (Rao et al. 1975), sudden intensity transitions (Boldt et al. 1974) and intensity dips around superior conjunction of the spectroscopic binary have also been established.

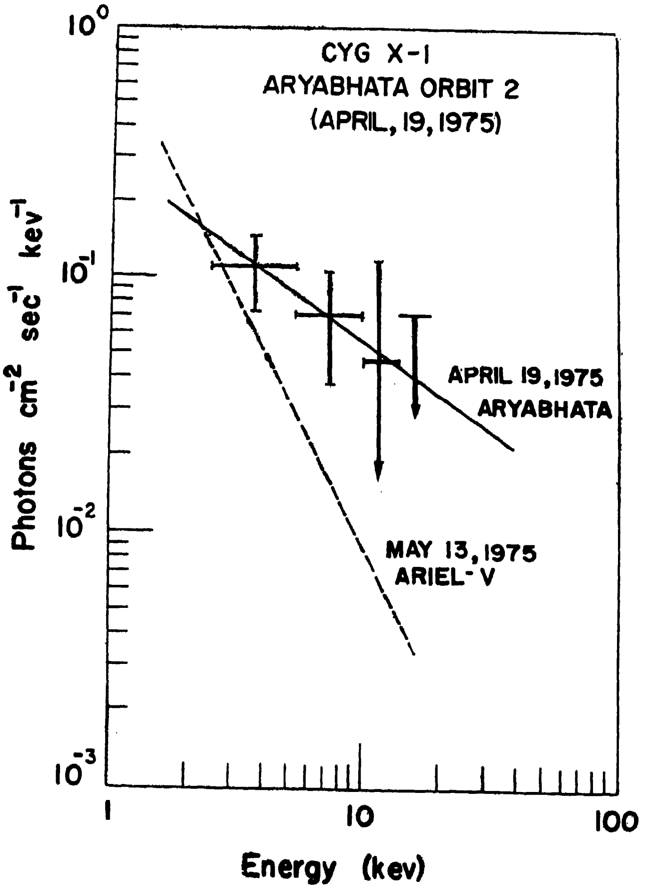

Fig. 1. The spectrum of Cyg X-1 as observed on 108^d 9^h 17^m 40^s UT (1975) prior to the transition.

Thorne and Price (1975) and Lightman and Eardley (1974) have attempted to interpret the intensity transition in Cyg X-1 in terms of the variable mass accretion from the OB supergiant onto the compact companion and the possible instabilities in the accretion disc. Further, dips in the intensity, observed in association with the superior conjunction of the binary by Parsignault et al (1975) resulting in spectral hardening, can arise from discrete absorption features such as gas streams of localized character (Pounds 1975). A hard spectrum of the type observed by Aryabhata can also result from such a situation. However, a single self consistent explanation is yet to emerge that can account for all the emission characteristics of Cyg X-1.

Another object of interest that was observed by Aryabhata, is GX 17+2, one of the relatively strong X-ray sources in the Scorpius-Sagittarius region. This source, earlier detected by UHURU, is very much akin to Sco X-1 in its emission properties. The emission is characterised by bremsstrahlung from hot plasma as suggested from the experimental nature of the energy spectrum. The characteristic kT value for this source as derived from the Aryabhata observations is $\sim$ 8 keV with an equivalent temperature of 93×10^6 °K.

GX 17+2 is one of the relatively strong X-ray sources in the Scorpius-Sagittarius region. This source has been previously observed in a number of experiments (Fisher et al. 1968, Schnopper et al. 1970) providing primarily information on its position rather than detailed emission features. The first set of detailed observations were made by Gorenstein et al. (1971) using UHURU detectors in late 1970 and early 1971 which revealed the variable character of X-ray emission from this source. More recent observations with a rocket borne payload by Hill et al. (1975) of the Lawrence Livemore Laboratory (LLL) have provided information about the thermal nature of its emission. Radio observations on this source by Hjellming and Wade (1971) when compared with the X-ray observations bring out the close similarity between GX 17+2 and Sco X-1. X-ray objects like GX 17+2 and Sco X-1 thus form a class by themselves that are characterised by X-radiation from a hot plasma and have a weak and variable radio emission.

The information from the solar neutron gamma ray experiment is also under detailed analysis. Preliminary examination of the data indicate the clear separation of the neutron and gamma ray induced events, one of the basic criterion for the usefulness of the data. The data will provide useful upper limits of neutron and gamma ray fluxes emitted from the quiet Sun. Also information on latitudinal distribution of high energy neutrons can be derived.

The information on solar neutron and gamma ray emission is of considerable interest to understand the nuclear reactions in the atmosphere of the Sun (Lingenfelter and Ramaty 1967). These nuclear reactions result in the production of neutral radiations, i.e. neutrons and gamma rays besides energetic charged particle radiation. In view of the fact that the neutrons and gamma rays are not affected by the interplanetary magnetic field, these radiations reach the earth directly, thus carrying information about the solar phenomenon.

(c) Application Experiments :—

A number of technological experiments, having relevance to future ISRO programmes have been successfully conducted during the last eight months.

The most important of these are the experiments conducted in relation to the satellite tracking. By a technique called tone ranging that involves the sending of different tones via the uplink to be received by the onboard receiver and retransmitted through the onboard transmitter back to the ground station, the line of sight distance to the satellite is now being routinely determined. The range of the satellite at any given time can be estimated with an accuracy of 3 km by comparing the transmitted and received tones. Another technique involving the Doppler principle has enabled the determination of the radial velocity of the satellites. The onboard transmitter being of high frequency stability, provided a suitable Doppler source for the computation of the radial velocity correct to 20 m/sec (the actual velocity of the satellite is about 8 km/sec). A third tracking experiment which involves interferometric technique has enabled the direction cones of the satellite to be determined to an accuracy of 6 minutes of an arc.

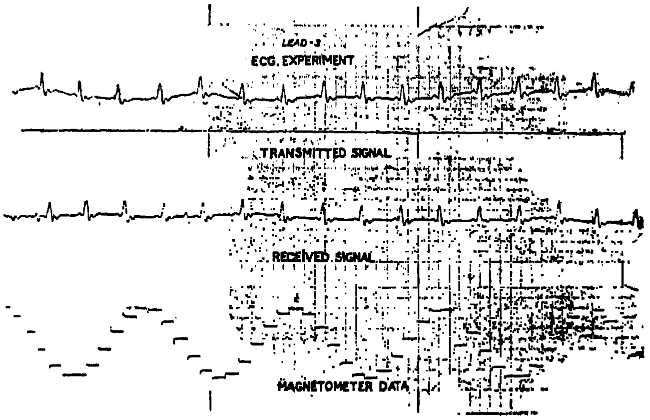

Fig. 2. A sample record of the electro-cardiogram signals received at Bangalore from SHAR via Aryabhata.

A voice communication experiment was conducted in which transmission of live messages was carried out between SHAR and Bangalore via Aryabhata. Similarly successful transmission of Electro-Cardiogram singals has also been accomplished between the two places primarily to demonstrate how satellites can be employed for providing medical help to rural areas. Fig. 2 shows the electro-cardiogram signals registered by the mini-ground station at Bangalore corresponding to the signals transmitted from SHAR via the onboard receiving and transmitting systems inside Aryabhata. More recently, Aryabhata was used to relay information on meteorological parameters from SHAR to Bangalore. A standard data collection platform for gathering meteorological information was used at the SHAR end.

CONCLUSIONS :

With the successful operation of Aryabhata in orbit for the last eight months, nearly all the primary mission goals of the satellite have been fulfilled, thus establishing indigenous capability in satellite technology. The satellite has already completed eight months of active life, well beyond the original design life of six months and is expected to be functional for a considerably longer period of time. Even the limited data obtained from two of the scientific experiments during the first few days of operation have provided interesting scientific information. The successful conduct of tracking and communication technological experiments have provided valuable experience from the standpoint of our future application technology programmes. Scientists in the country can thus look forward with confidence to the availability of expertise in this area of sophisticated technology for carrying out meaningful scientific and application experiments from space.

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