

PSLV-C2 mission

S. Ramakrishnan, R. N. Tyagi, S. S. Balakrishnan and Sojan Thomas*

The fifth Indian Polar Satellite Launch Vehicle mission, PSLV-C2, which took off on 26 May 1999, at 1152 h IST, marks an important milestone in the Indian Space Programme. This is the first time that an Indian launch vehicle carried multiple satellites, one primary satellite IRS-P4, a 1036 kg Indian Remote Sensing Satellite (IRS-P4) or OCEANSAT-1; and two auxiliary payloads into 720 km polar Sun-Synchronous Orbit (SSO).

The two auxiliary payloads or microsatellites were the KITSAT-3, weighing about 107 kg, developed by the Satellite Technology Research Centre, Korea Advanced Institute of Science & Technology, Republic of Korea, and the DLR-TUBSAT, weighing 45 kg, developed by Technical University of Berlin (TUB) and German Space Centre (DLR). With the successful launch of these microsatellites by ISRO, its entry into the multi-million commercial launch services market has been signalled.

This article gives the details on the PSLV-C2 mission; highlighting the studies, changes, and preparation made with reference to launch of auxiliary satellites along with the main satellite.

PSLV-C2 mission: Flight no. 5

PSLV is a four-stage vehicle, that employs solid and liquid stages alternately (Figure 1). After three developmental missions, the fourth mission of PSLV (PSLV-C1) placed the operational IRS-1D satellite into polar orbit during September 1997. Incidentally, PSLV-C1 was the first launch in PSLV Continuation Programme, under which the Government had approved the production of 9 vehicles.

Changes from C1 to C2 mission

This section provides the modifications carried out on the PSLV equipment bay to accommodate the auxiliary satellites, development of the satellite separation system, structural tests to analyse the adequacy of the satellite structure, and on the mission analyses performed to ensure collision-free separation even under worst conditions.

Accommodation of auxiliary satellites

PSLV configuration used for the C2 mission was the same as that was flown in the previous mission. But to accommodate the auxiliary payloads, provision was made on the vehicle equipment bay (VEB), on diametrically opposite sides to carry up to two microsatellites

(< 100 kg, 600 × 600 mm size, and 800 mm ht.) in a piggy-back mode. This will be used as a standard arrangement for all the future flights, in order to enable piggy-back ride for this class of satellites, for scientific and technology-providing missions (Figure 2).

Separation system for auxiliary satellites

To mount the auxiliary satellites on the VEB and to separate them, ball-lock separation systems, 358 mm dia for KITSAT-3 and 230 mm dia for DLR-TUBSAT, were developed and tested. The ball-lock mechanism consisted of two rings, the inner ring attached to the bottom surface of the satellite and the outer ring attached to the VEB. These two rings were held together by a number of hardened steel balls which locked the inner race to the outer ring. Redundant pyrothrusters rotate the outer ring by about 4° to cause the radial escape of the balls through aligned holes, thereby releasing the inner ring attached to the satellite. The separation velocity to the auxiliary payload was provided by the energy stored in the compressed springs, which were located symmetrically at the interface. A nominal velocity of 1.0 m/s was imparted to the microsatellites.

Structural model test

The above configuration changes incorporated for the microsatellites required validation of these changes. For this, the fourth stage along with mock-up equipment bay and the structural models of KITSAT-3 and DLR-TUBSAT were stacked, in order to check for their

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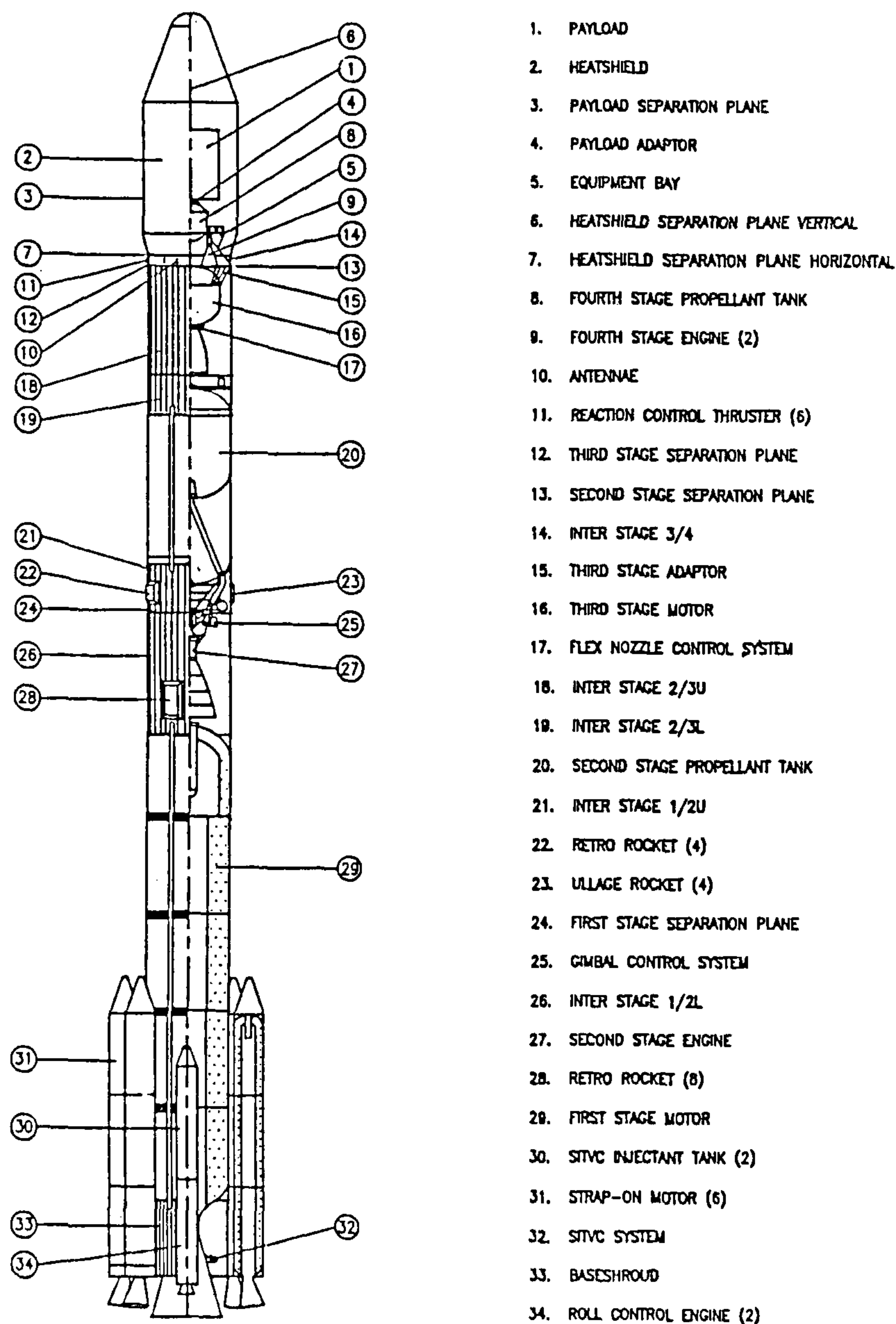


Figure 1. The Polar Satellite Launch Vehicle (PSLV): The various stages.

mechanical and electrical interfaces compatibility, and were vibrated (both sine and random vibrations) in order to determine the characteristics along longitudinal and lateral axes of the spacecraft. This test also provided input for coupled load analysis and responses at critical locations on the spacecraft.

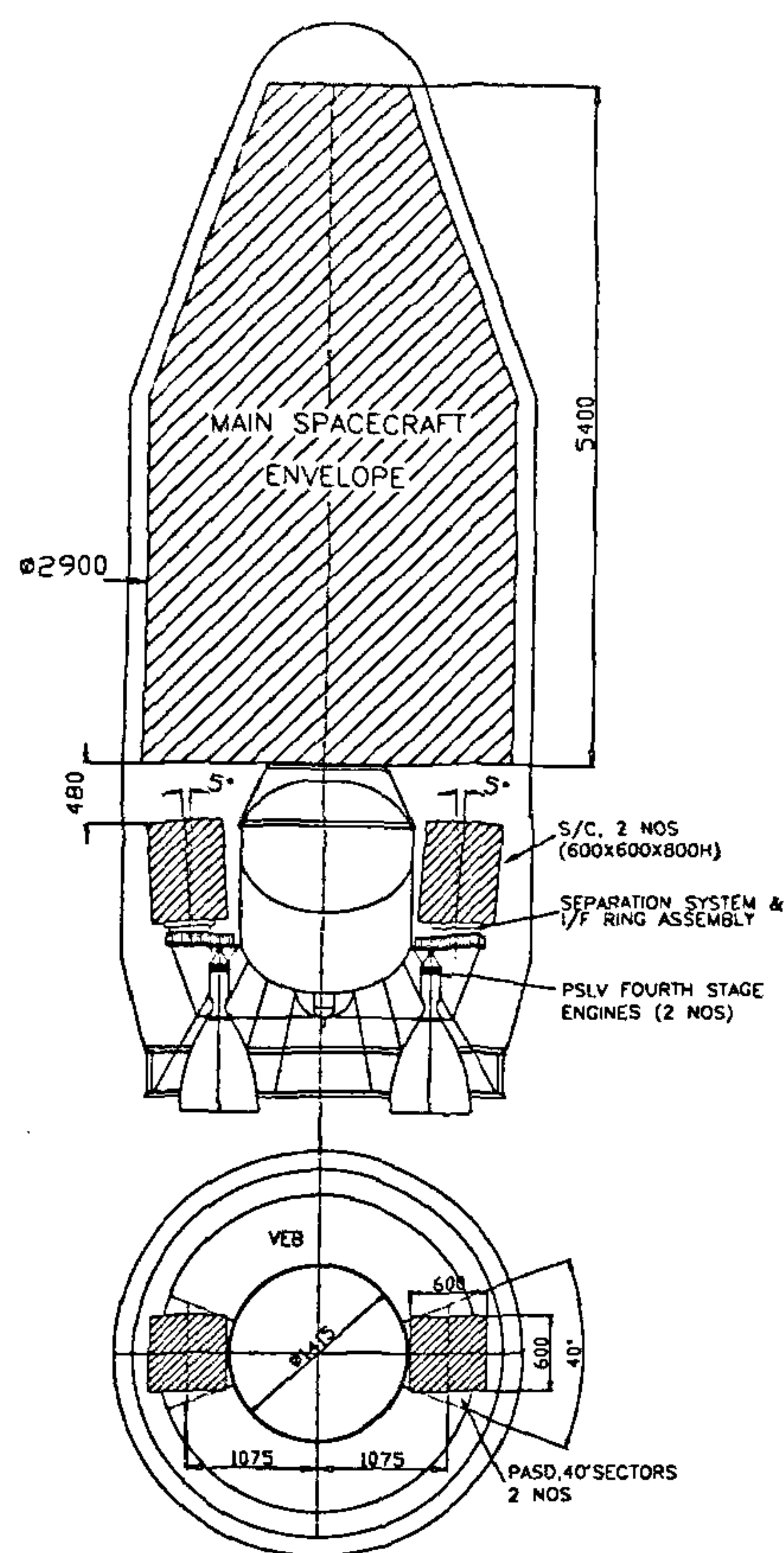
Separation test

The vibrated stack was tested for separation of satellites, and also for the measurement of spacecraft separation velocities and shock levels at the spacecraft interface and on the vehicle equipment bay.

Mission analysis

The mission analysis performed the following:

- Coupled load analysis for loads and frequency adequacy of the satellite structures.
- Spacecraft dynamic separation analysis for worst case conditions without collision with the vehicle stage.
- The rotational velocities imparted to the separating satellite(s) under worst case conditions.
- Long-term propagation of relative motion among the various satellites: OCEANSAT; KITSAT-3; and DLR-TUBSAT.



AUXILIARY PAYLOADS ON EQUIPMENT BAY

Figure 2. Auxiliary payloads on equipment bay.

A detailed Monte Carlo analysis was conducted considering dispersion values for various parameters like CG offsets, MI, mass, clearance between satellite face and the 4th-stage tankage, differential spring velocities, etc. and a positive design margin was established.

A brief summary of the characteristics of PSLV stages is given in Table 1.

PSLV-C2: Flight 05 trajectory

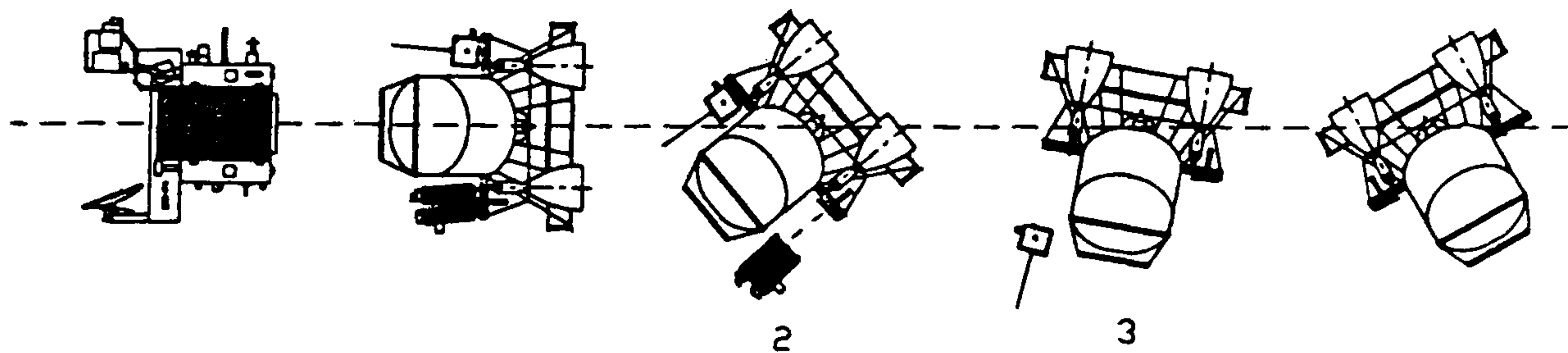
The trajectory design features of PSLV-C2 are such that they allow the launcher to ascend vertically up to T+5 s. After this, the vehicle is supposed to roll by 5° to orient itself towards 140° Azimuth with reference to true north, and is supposed to pitch down as per the pre-determined pitch program stored on-board.

At the end of I-stage burn and ignition of the 2nd stage, the vehicle would be maneuvered in yaw plane also in order to orient the vehicle in such a way that it would reach the mission inclination upon injection. During the II-stage burn, at T + 162 s, the heat shield would be jettisoned at an altitude > 115 km. After this, the vehicle closed loop guidance (CLG) system would steer the vehicle till the injection of the satellite(s). To cater to performance deviations of the lower three stages, sufficient guidance margin, by way of additional fuel, has been provided in the IV-stage and, thus, CLG would ensure the right orbit as long as the vehicle dispersions are within 3σ bound.

Soon after the guidance cut-off of the 4th stage, with the achievement of the mission target parameters, the IRS-P4 would get separated followed by the separation of auxiliary satellites KITSAT-3 and DLR-TUBSAT

Table 1. Overall characteristics of PSLV

	Strap-on boosters (PSOM)	Stage 1 (PS1)	Stage 2 (PS2)	Stage 3 (PS3)	Stage 4 (PS4)
Dimensions					
Length (m)	11.3	20	12.5	3.6	2.6
Diameter (m)	1.0	2.8	2.8	2.0	2.0
Mass					
Propellant (T)	6 × 9.0	138	40.5	7.3	2.1
Gross (T)	66.0	168.0	45.8	8.4	3.0
Structure					
Material	High strength steel	High strength steel	Aluminium alloy	Composite	Titanium
Propulsion					
Number of engines	6 motors	1	1	1	2
Propellant	HTPB-based solid	HTPB-based solid	UDMH & N ₂ O ₄	HTPB-based solid	MMH & MON
Average thrust (kN)	677	4430	724	324	2 × 7.4
Attitude control					
Pitch	—	SITVC	{ Engine	{ Flex nozzle	{ Engine
Yaw	—	SITVC	{ gimballing	{ control	{ gimballing
Roll	SITVC	RCS	Hot gas	RCS	RCS



1. SEPARATION OF IRS-P4
2. SEPARATION OF KITSAT AFTER YAW TURN OF -40 DEG
3. SEPARATION OF TUBSAT AFTER A YAW TURN OF -80 DEG
4. SPENT PS4 STAGE YAW TURN -120 DEG

Figure 3. Separation sequence of satellites.

Table 2. The values of predicted and actual orbit

Parameter	Pre-flight prediction	Actual
Perigee (km)	727 ± 35	723.1
Apogee (km)	727 ± 35	735.1
Inclination (deg)	98.286 ± 0.2	98.38

following pre-fixed yaw maneuvers to avoid collision. The sequence of separation is depicted in Figure 3.

Based on the injection state available from the on-board inertial navigation system, the down-range radar and the s-band telemetry tracking, the preliminary orbits have been determined for further acquisition of satellites by the respective satellite agencies. The total mission from take-off would be about 1150 s.

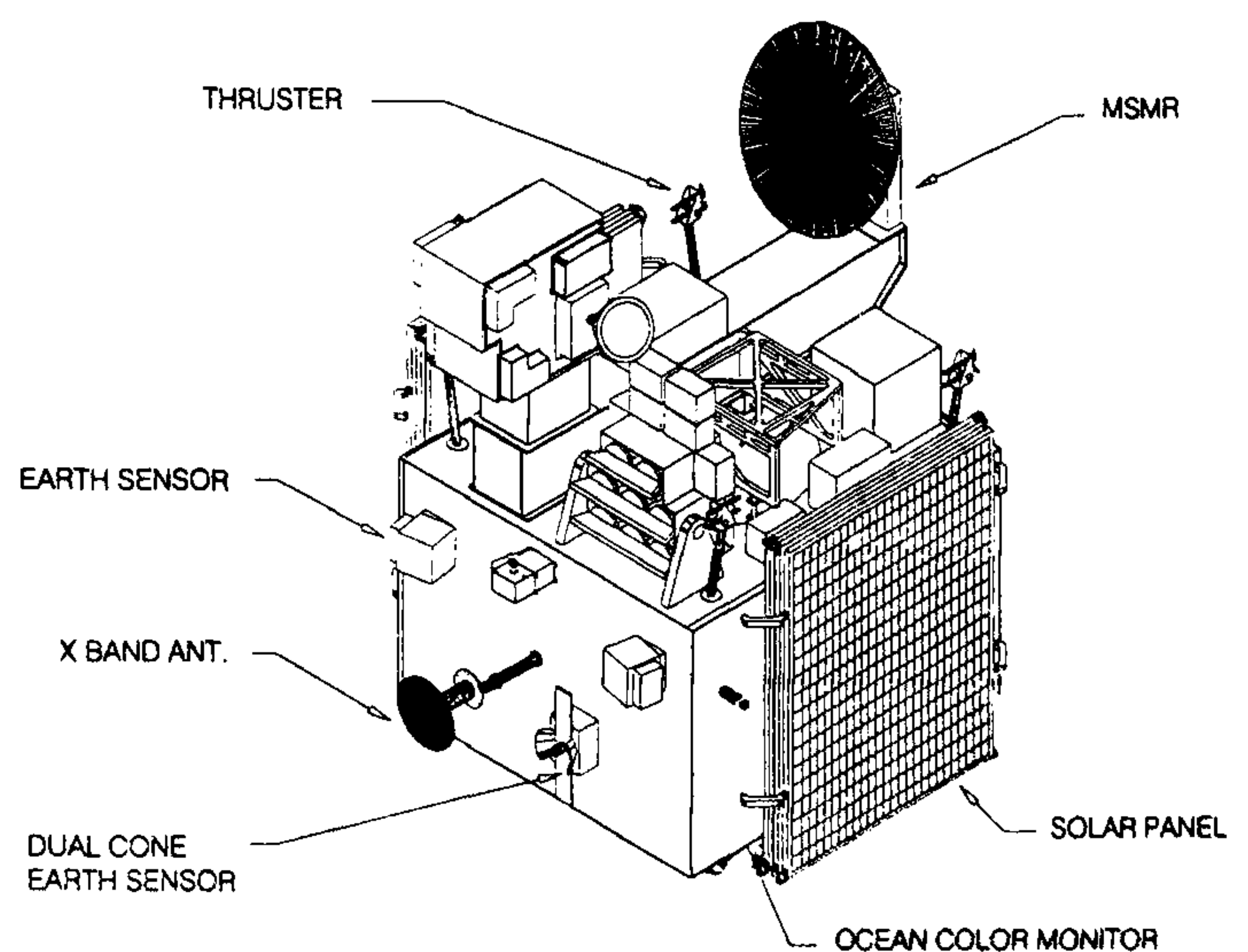
The values of predicted and actual orbit obtained have been listed in Table 2.

IRS-P4 – (OCEANSAT) satellite

IRS-P4 is the eighth in the series and the first one dedicated for ocean studies. It carried an Ocean Colour Monitor (OCM) and Multifrequency Scanning Microwave Radiometer (MSMR) for ocean-related applications, and hence was named OCEANSAT-1. The stowed view of IRS-P4 is given in Figure 4.

The mission objectives

- To gather data for oceanographic, land (vegetation dynamics) and atmospheric applications.
- To provide new application areas using data as complementary/supplementary to the already operating remote sensing satellites.



IRS-P4
STOWED CONFIGURATION

Figure 4. IRS-P4.

To provide opportunity for conducting technological/scientific experiments that are of relevance to future developments.

Salient features

Orbit	: Polar sunsynchronous orbit
Altitude (km)	: 727
Inclination (deg)	: 98.286
Period (min)	: 99.3
Launch time	: 1140 h IST

Coverage cycle	: 2 d
Mass at lift-off (kg)	: 1050
Size (m)	: Cuboid of $2.8 \times 2.0 \times 2.6$
Length when fully deployed (m)	: 11.7
Power (W)	: 750
Attitude and orbit control	: 3-axis body-stabilized using reaction wheels, magnetic torquers and hydrazine thrusters
Mission life	: 5 years

After launch, the satellite has been under the control of ISRO Telemetry, Tracking and Command Network (ISTRAC) at Bangalore and the payload data is being received at the National Remote Sensing Agency (NRSA), Hyderabad.

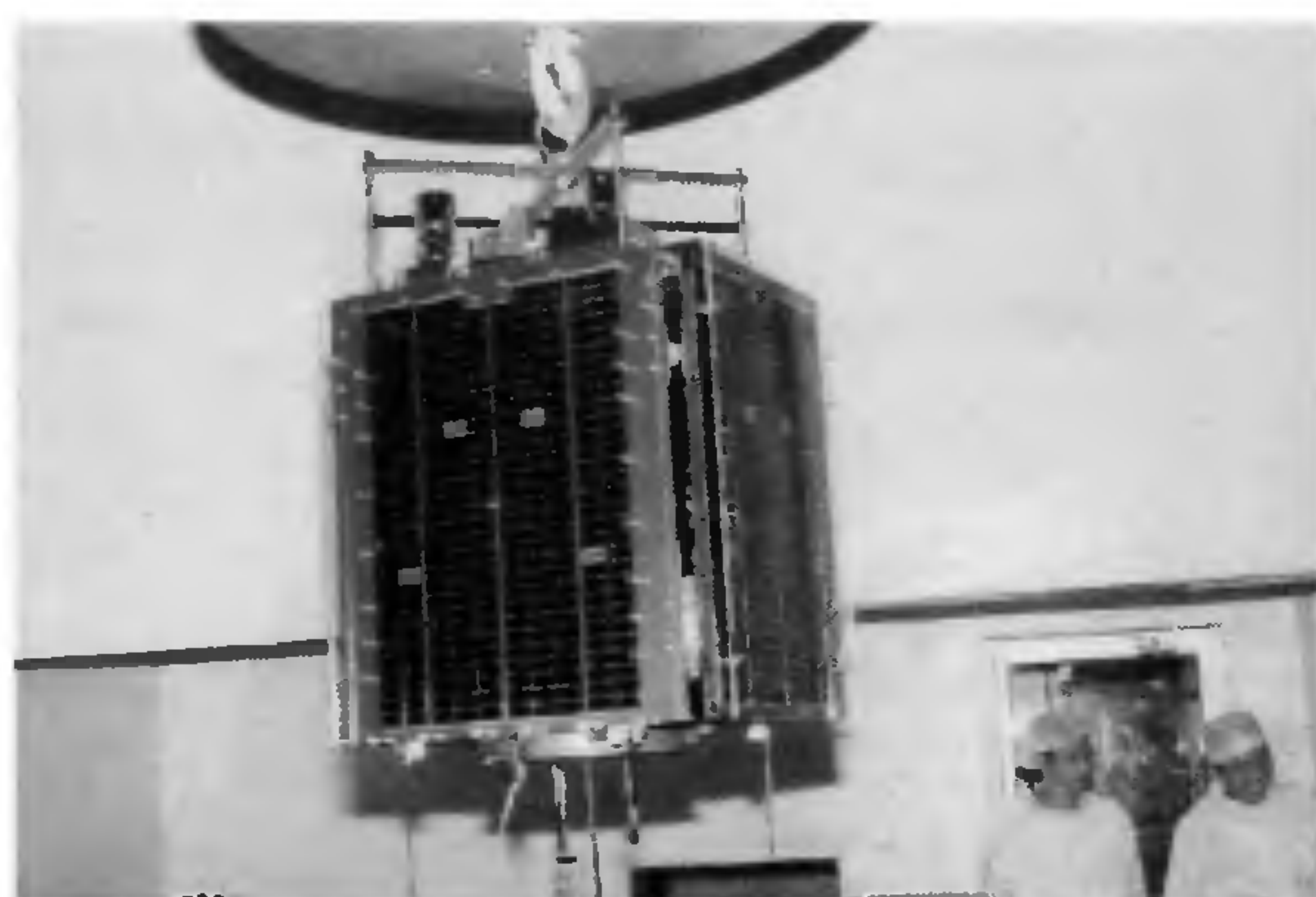


Figure 5. A view of the fully assembled KITSAT-3.

Auxiliary payloads

KITSAT-3

KITSAT-3 is an engineering test satellite whose primary mission objective has been to develop various fundamental technologies for high performance microsatellites to qualify them in the low-earth-orbit space environment.

It was developed by the Satellite Technology Research Center (SaTReC), Korea and the Advanced Institute of Science and Technology (KAIST), Republic of Korea. The view of the fully assembled KITSAT-3 is shown in Figure 5 and the exploded view in Figure 6.

Summary of major features

The major features of KITSAT-3 are summarized as follows:

- Mass : < 110 kg
- Dimension : $495 \times 630 \times 854(H)$ mm
- Power : 150 W max.
(1 fixed and 2 deployable solar panels)
- Common bus architecture
- 3-axis stabilized attitude control
(pointing accuracy $< 0.5^\circ$)
- Attitude sensors:
star sensors, sun sensor, IR earth horizon sensor, magnetometers, fiber optic gyros
- Attitude control actuators:
Magnetorquers, reaction wheels
- GPS navigator

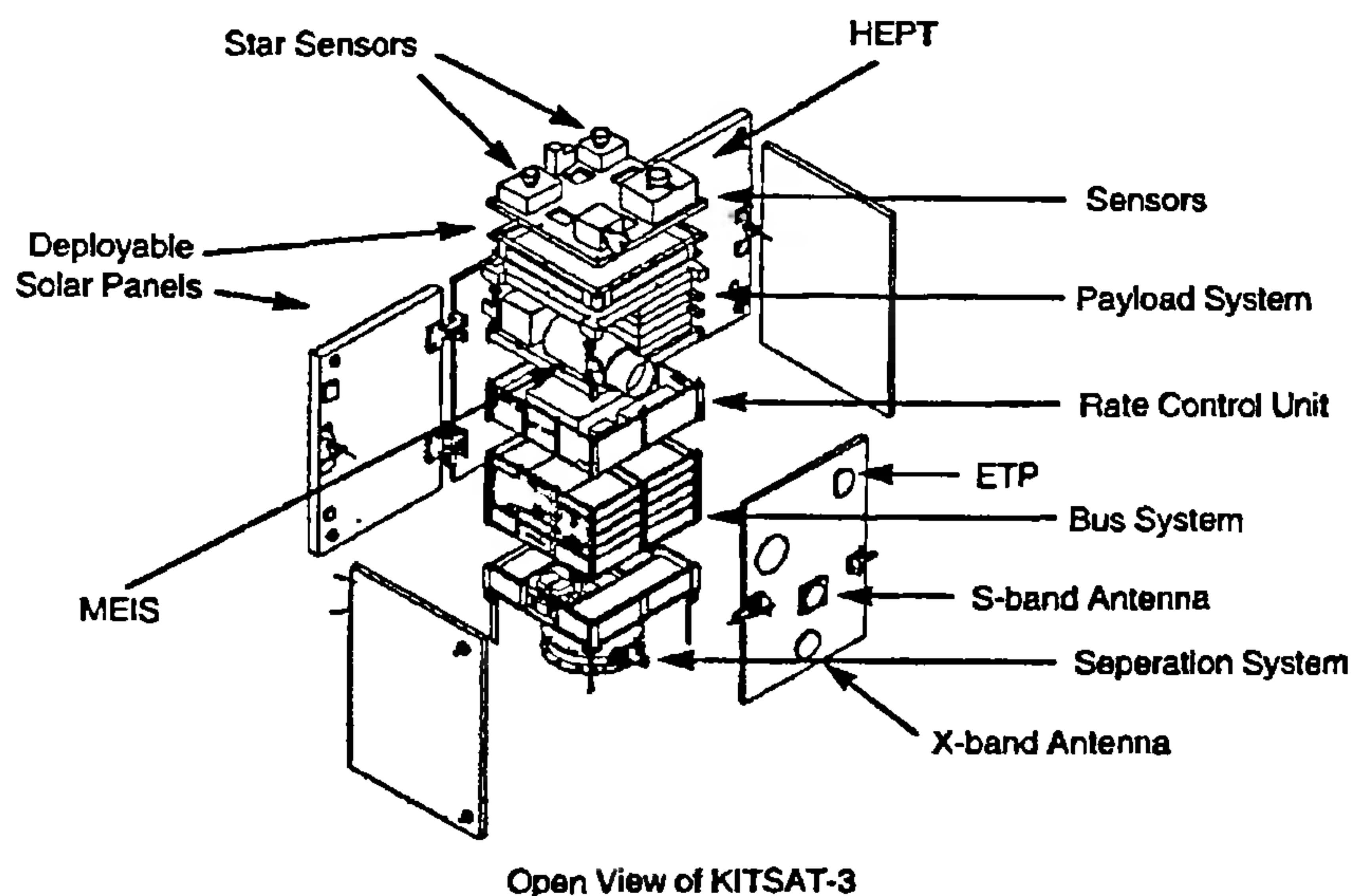


Figure 6. Exploded view of KITSAT-3.

- Data transmission systems
 - 38.4 kbps in S-band
 - 3.2 Mbps in X-band
- Solid-state mass memory
 - 2 Gbits SRAM
 - 8 Gbits flash memory
- Mission payloads:
 - Multi-spectral Earth Imaging System (MEIS)
 - Space Environment Scientific Experiment (SENSE)

Multi-spectral Earth Imaging System

The MEIS consists of a catadioptric telescope, prism blocks, focal plane assembly, video signal processing electronics, camera flight processors (CFP), and solid-state mass memory units. The MEIS is of push-broom type and produces images of the earth's surface in three spectral bands. Its main characteristics are:

- Weight: 6.5 kg (3 kg for telescope)
- Power: 15 W
- Detector: Three linear CCDs with 3456 pixels
- IFOV: 19.1 μ rad (GSD \sim 15 m)
- FOV: 3.8° (swath width \sim 50 km)
- Spectral bands: 520–620, 620–690, 730–900 nm
- Effective focal length: 570 mm
- F number: 5.7
- MTF: 20% at nyquist frequency

Space Environment Scientific Experiment

The SENSE consists of the following four sub-systems.

- High-Energy Particle Telescope (HEPT)
- Radiation Effects on Micro-Electronics (REME)
- Scientific MAGnetometer (SMAG)
- Electron Temperature Probe (ETP)

HEPT is not only being used to measure the particle energy entering the telescope but also has the capability to identify the particle species. Four silicon detectors have been used along with blocking materials of aluminium and copper, which are being used to control the particle energy reaching each detector. Moreover, it can also measure the pitch angle distribution of particle energies.

REME consists of TDE monitor and SEU monitor units. While the TDE monitor is being used to measure the long-term accumulated ionizing radiation dose in SiO₂ for three locations in the KITSAT-3 bus, the SEU monitor is being used to perform, a series of testing to measure the SEU characteristics of memory devices.

SMAG is being used to measure the magnetic field using a flux-gate type sensor and is also being used as a diagnostic tool for global and local geomagnetic distur-

bance and current systems, low frequency waves in the ambient environment, and of the wave-particle interaction. Thus it will provide the information on the magnetic field direction for HEPT and plasma gyro-frequencies.

ETP is being used to measure the electron temperature in high latitude regions. It was specifically developed in order to study the occurrence of anomalous heating phenomenon found in the South Atlantic Anomaly, as well as to find any relationship it has with other plasma parameters such as energetic particles and plasma waves.

Post-launch operation

KITSAT-3 was separated from the VEB deck after the separation of the IRS-P4. After 3.5 h, the telemetry was switched on and the first contact with the command ground station in Korea was at 7.5 h after the separation. After the spacecraft health checks were completed, the solar panel was deployed producing full power of 180 W required for operations. The first set of pictures that have been received reveal the quality of the pictures. These pictures can be viewed at the web site <http://satrec@kaist.ac.kr>.

DLR-TUBSAT

The microsatellite DLR-TUBSAT was jointly developed by the Technical University of Berlin (TUB) that was responsible for the satellite and the German Aerospace Centre (DLR) that was responsible for the payload.

The cube-shaped satellite measures 32 \times 32 \times 32 cm and weighs 45 kg. The task of the satellite is earth observation with high resolution (better than 10 m ground pixel resolution). The satellite is being operated from the TUB Satellite Control Centre.

DLR-TUBSAT has a payload module, a power module and an attitude control module. The exploded view is shown in Figure 7.

The payload module contains two fore field sensors with low- and medium-resolution telescope and a high-resolution telescope with a focal length of 1 m, a pixel size of 8.3 μ m and a ground pixel resolution of 7 m. Each CCD-chip contains 752 \times 582 pixel, and each camera can transmit both video images in CCIR-standard and signal digital pictures. The focal length of the fore field cameras is 16 mm and 50 mm respectively. The S-band antenna is physically located on the attitude control module in order not to obstruct the field of view of the payload sensors, and the S-band transmitter is located close to the antenna. For the transmission of pictures using analog video, a bandwidth of 8 MHz has been selected and the transmission of single pictures occurs at 128 kbaud. The beamwidth of the antenna is 70°.

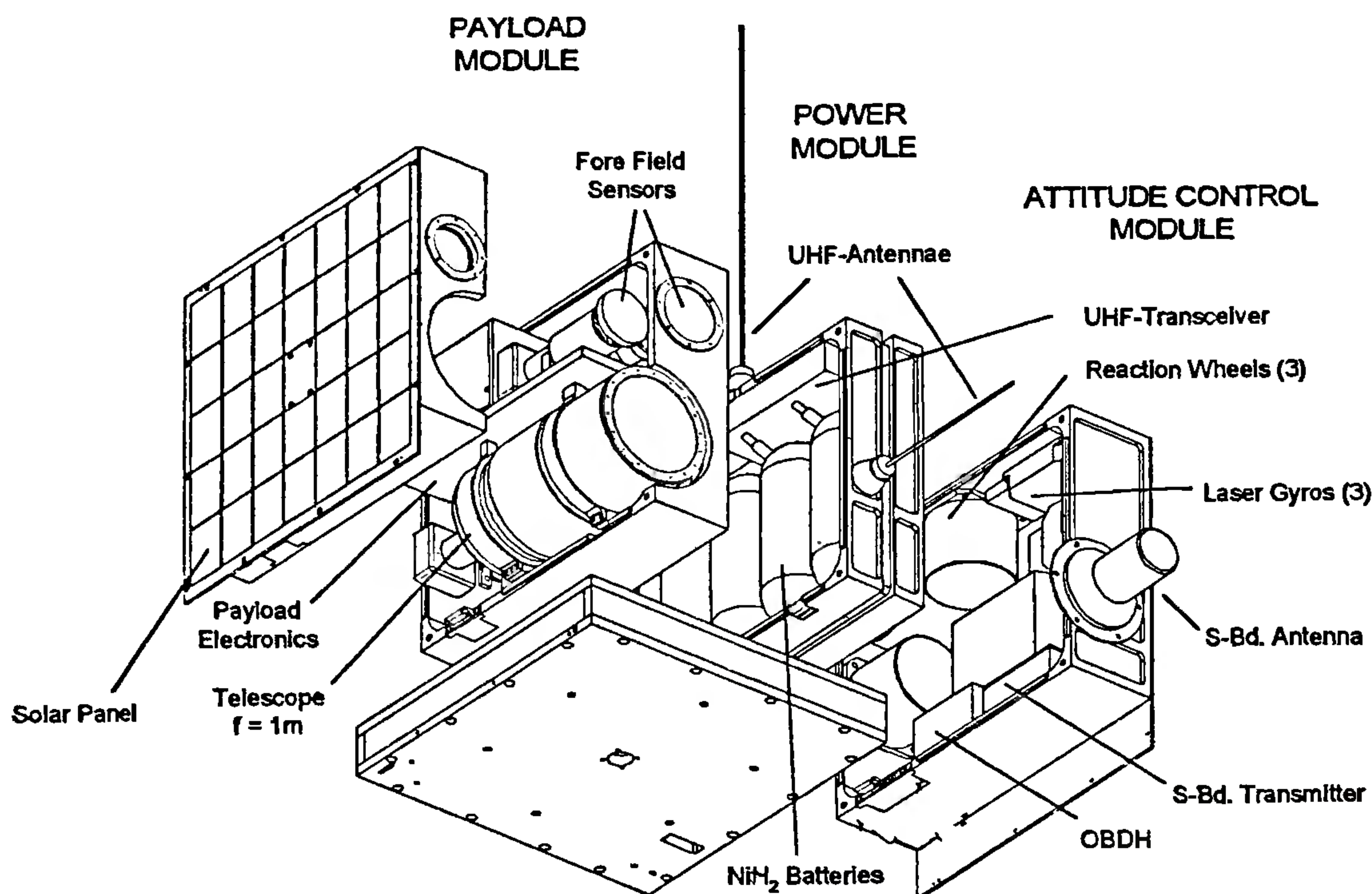


Figure 7. Exploded view of DLR-TUBSAT.

The power module contains the batteries, the power control unit, and two UHF transceivers as well as two UHF antennae. Four duplex NiH₂ battery cells of 12 Ah capacity have been used to support an unregulated 10 V bus that is charged by four identical solar panels, each containing a single string of 34 silizium solar cells. The supply of short circuit current to each of the panels is 960 mA. The UHF transceiver receives and transmits data via FFSK modulation at a rate of 1200 baud. Each of the transceivers has been connected to one of the UHF antennae. Both the transceivers are nominally operating in parallel, in a listening mode. As long as no order is received from the ground, the satellite remains silent.

The attitude control module includes three reaction wheel-gyro pairs as well as the on board data handling system (OBDH). The OBDH system is being used to transmit targets (angles or angular rates) to the control loops within the reaction wheels. The targets can also be set by ground command.

In its standby (hibernation) mode, the satellite tumbles at a natural rate of typically 0.1 rpm. The acquisition sequence will start with a rate reduction command, followed by a coarse sun acquisition maneuver, using the information of the solar arrays and a coarse earth acquisition maneuver using the same (albedo) informa-

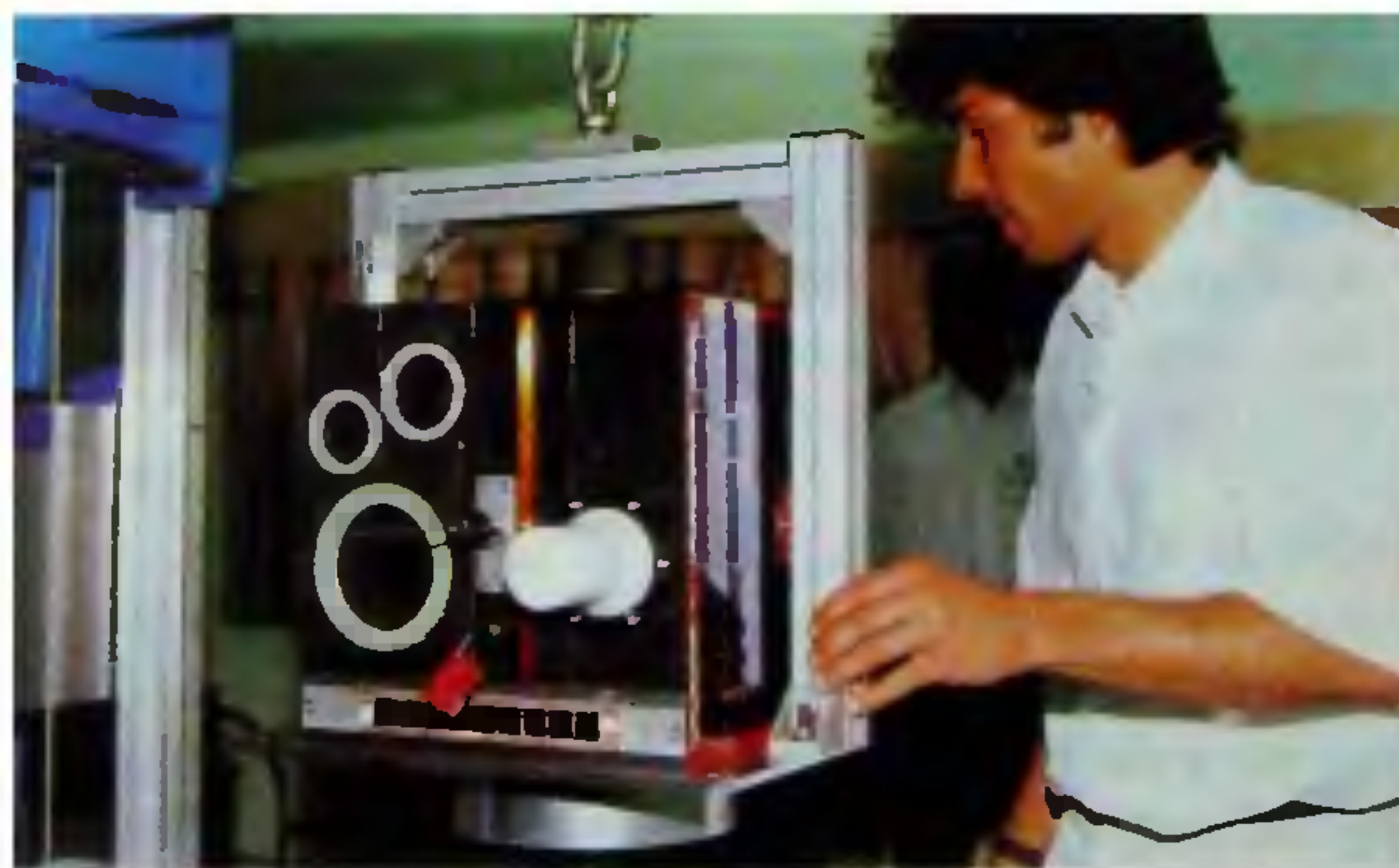


Figure 8. Fully assembled view of the DLR-TUBSAT.

tion. This will be followed by the TV transmission and the user on the ground can interactively steer via the wheel-gyro pairs, in a rate-control mode, pointing towards any interesting scene on the ground. Once satisfied with the view, a photo can be commanded with high, medium (colour) or low resolution. The fully assembled view of the DLR-TUBSAT is shown in Figure 8.

A ball-lock type separation system has been attached to the bottom plate of the satellite in order to eject the satellite with a separation velocity of approximately 1 m/s. The unit with a pitch circle diameter of 23 cm is supplied by Antrix/ISRO.

PSLV injected DLR-TUBSAT, after the separation of both IRS-P4 and KITSAT-3, about 127 s after cut-off the 4th stage.

During the launch phase however, the NiH_2 batteries were discharged for safety reasons. After separation from the launcher, as per the plan, the solar panels are used to recharge the batteries within the following 7 h. However, contrary to the planned schedule, the DLR-TUBSAT was tracked on the 2nd orbit itself and the telemetry was received over the university ground station in Berlin. Since then, the satellite has been functioning very well and good pictures are being received from the on-board cameras.

Conclusion

With the demonstration of the fourth consecutive successful launch, PSLV has established its versatility. It

can provide multiple launches to Low Earth Orbit (LEO), polar sun-synchronous missions and also for Geo-synchronous Transfer Orbit (GTO) missions. The payload capability is more than 3000 kg in 400 km LEO, up to 1200 kg polar at 800 km altitude and 850 kg in GTO. Further planned improvements of PSLV are:

- A high performance upper stage by this year end which would increase the payload capability further in all the above orbits.
- A single engine version of the 4th liquid stage to increase the payload volume inside the heat shield by about 25%.
- A dual launch adapter to utilize the above-increased payload volume to enable the launch of a mix of payloads

With the above and the PSLV-C2 mission success, PSLV has opened the way for dedicated commercial launch services for bigger and heavier satellites.

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Molecular markers and their applications in livestock improvement

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Recent developments in DNA technologies have made it possible to uncover a large number of genetic polymorphisms at the DNA sequence level, and to use them as markers for evaluation of the genetic basis for the observed phenotypic variability. The markers revealing variations at DNA level are referred to as the molecular markers. Based on techniques used for detection, these markers are classified into two major categories: Hybridization-based markers and PCR-based markers. The molecular markers possess unique genetic properties and methodological advantages that make them more useful and amenable for genetic analysis compared to other genetic markers. The possible applications of molecular markers in livestock improvement have been reviewed with reference to conventional and transgenic breeding strategies. In conventional breeding strategies, molecular markers have several short-range or immediate applications and long range applications. In transgenic breeding, molecular markers can be used as reference points for identification, isolation and manipulation of the relevant genes, and for identification of the animals carrying the transgenes. The progress in development of molecular markers suggests their potential use for genetic improvement in livestock species.

THE progress in recombinant DNA technology and gene cloning during the last two decades has brought in

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revolutionary changes in the field of basic as well as of applied genetics by providing several new approaches for genome analysis with greater genetic resolution. It is now possible to uncover a large number of genetic polymorphisms at the DNA sequence level, and to use