GSLV-D3 / GSAT-4 MISSION

Background

GSLV-D3 is the third developmental mission of India's Geosynchronous Satellite Launch Vehicle during which ISRO's indigenously developed Cryogenic Upper Stage (CUS) will be flight tested. In this flight, GSLV is scheduled to launch 2220 kg GSAT-4, an experimental advanced technology communication satellite that carries communication and navigation payloads, into Geosynchronous Transfer Orbit (GTO). GSLV, carrying the indigenous CUS, is designated as GSLV MkII. Envisaged mainly as a technology demonstrator for advanced satellite communications, GSAT-4 will enable the testing of many future communication satellite technologies. After reaching GTO, GSAT-4 will use its own propulsion system to reach its geostationary orbital home and will be stationed at 82 deg East longitude there.

GSLV-D3 Mission

GSLV-D3 is the sixth flight of ISRO's Geosynchronous Satellite Launch Vehicle (GSLV) as well as its third developmental flight. Major changes incorporated in GSLV-D3 compared to its previous flight (GSLV-F04) include:

- **Indigenous Cryogenic Upper Stage**
- **Advanced Telemetry System and Advanced Mission Computers**
- **Larger Composite Payload Fairing**

GSLV-D3 is the maiden flight of GSLV in which the indigenous Cryogenic Upper Stage (CUS) is used. In the past five flights of GSLV, Cryogenic Stages (CS) procured from Russia were used. GSLV, with the Russian CS, was designated as GSLV MkI, whereas the present GSLV carrying the indigenous CUS is designated as GSLV MkII.

GSLV was designed to inject 2 ton class of communication satellites to Geosynchronous Transfer Orbit (GTO). Usually, geostationary satellites are first injected into the elliptical GTO by launch vehicles. Later, the satellites are taken to the circular Geostationary Orbit using their own propulsion system. Geostationary Orbit lies at a height of 36,000 km over the equator.

The 50 m tall GSLV, with a lift-off mass of 416 ton, is a three-stage vehicle with solid, liquid and cryogenic stages. The solid core motor of the first stage of GSLV is one of the largest rocket motors in the world and

uses 138 tons of Hydroxyl Terminated Poly-Butadiene (HTPB) based propellant (fuel-oxidiser combination). The second stage (carrying 38.5 tons of propellant) as well as the four strap-on motors of the first stage
(each carrying 42 tons of propellant) use liquid propellant 'Vikas' engine burning UH25 and Nitrogen Tetroxide. The third stage of GSLV carrying 12.5 tons of propellants is a cryogenic stage that uses liquid Hydrogen as fuel and liquid Oxygen as oxidiser.

GSLV employs S-band telemetry and C-band transponders for enabling vehicle performance monitoring, tracking, range safety/flight safety and Preliminary Orbit Determination (POD).

The Composite Carbon Fibre-Reinforced Plastic Payload Fairing (PLF), which is 8.657 m long and 4 m in diameter, protects the satellite and the vehicle electronics during its ascent through the atmosphere. It is jettisoned when the vehicle has reached an altitude of about 115 km. In the earlier flights of GSLV, a metallic PLF of 3.4 m diameter was used.

The Redundant Strap Down Inertial Navigation System (RESINS MkIV) / Inertial Guidance System (IGS), housed in the equipment bay of GLSV, guides the vehicle from lift-off to satellite injection. The digital auto-pilot and closed-loop guidance scheme ensure the required attitude manoeuvre and guided injection of the satellite to the specified orbit.

GSLV employs various separation systems such as Flexible Linear Shaped Charge (FLSC) for the first stage, pyro actuated collet release mechanism for the second stage and Merman band bolt cutter separation mechanism for the PLF. Spacecraft separation is by spring thusters mounted at the separation interface.

Besides having the indigenous Cryogenic Upper Stage for the first time, in another major change, GSLV-D3 is carrying Advanced Mission Computer (AMC) and Advanced Telemetry System (ATS) packages.

GSLV-D3 will be launched from the Second Launch Pad (SLP) at Satish Dhawan Space Centre SHAR, Sriharikota.

Indigenous Cryogenic Upper Stage

GSLV-D3 flight is significant since the indigenously developed Cryogenic Upper Stage (CUS) is flight tested in this mission. This is the first time GSLV is carrying the indigenous CUS as its third stage instead of the Russian supplied Cryogenic Stage (CS), which was carried during its earlier flights.

Cryogenic Stage is a rocket stage that is much more efficient and provides more thrust for every kilogram of propellant it burns compared to solid and earth-storable liquid propellant stages. Specific impulse (a measure of the efficiency) achievable with cryo fluids (liquid Hydrogen and liquid Oxygen) is of the order of 450 sec compared to 300 sec for earth storable and solid fuels, giving a substantial payload advantage; for an upper stage, with every one second increase in the specific impulse, the payload gain is of the order of 15 kg.

However, cryogenic stage is technically a very complex system compared to solid or earth-storable liquid propellant stages due to the use of propellants at extremely low temperatures and the associated thermal and structural problems. Oxygen liquifies at -183 deg C and Hydrogen at -253 deg C. The propellants, at these low temperatures, are to be pumped using turbo pumps running at around 40,000 rpm. It also entails complex ground support systems like propellant storage and filling systems, cryo engine and stage test facilities, transportation and handling of the cryo fluids and related safety aspects.

ISRO's Cryogenic Upper Stage Project (CUSP) envisaged the design and development of the indigenous Cryogenic Upper Stage to replace the stage procured from Russia and used in GSLV flights. CUSP was intended to develop a cryogenic stage with regenerative cooled engine, producing a thrust of 69.5 kilo Newton (kN) in vacuum. As part of this effort, cryogenic engines were realised and tested earlier for a cumulative duration of 7760 sec. In the stage level hot test, apart from cryogenic engine, all other stage elements worked in unison as per flight standards.

In December 2008, a major milestone was achieved with the flight acceptance hot test of the indigenous Cryogenic engine. This hot test was an importance step in acquiring a coveted status for the country among space faring nations which have successfully mastered this critical and most complex technology. With this, India came a step closer to becoming totally self reliant in all aspects of launch vehicle technology.

The indigenous Cryogenic Upper Stage (CUS) is powered by a regeneratively cooled cryogenic engine, which works on staged combustion cycle. This main engine, and two smaller (cryogenic) steering engines together develop a nominal thrust of 73.55 kN in vacuum. The main engine of CUS achieves a specific impulse of 452 seconds. During the flight, CUS fires for a nominal duration of 720 seconds.

Along with the main engine and the two steering engines, the other stage systems of CUS include insulated propellant tanks, booster pumps, inter-stage structures, fill and drain systems, pressurisation systems, gas bottles, command block, igniters, pyro valves and cold gas orientation and stabilisation system.

Liquid Oxygen (LOX) and Liquid Hydrogen (LH2) from the respective tanks are fed by individual booster pumps to the main turbo-pump, which rotates at 39,000 rpm to ensure a high flow rate of 16.6 kg/sec of propellants into the combustion chamber. The main turbine is driven by the hot gas produced in a pre-burner. Thrust control and mixture ratio control are achieved by two independent regulators. LOX and Gaseous Hydrogen (GH2) are ignited by pyrogen type igniters in the pre-burner as well as in the main and steering engines during initial stages.

Apart from the complexities in the fabrication of stage tanks, structures, engine and its subsystems and control components, CUS employs special materials like Aluminum, Titanium, Nickel and their alloys, bi-metallic materials and polyimides. Stringent quality control and elaborate safety measures have to be ensured during assembly and integration.

GSAT-4: The Satellite

GSAT-4 is the nineteenth geostationary satellite of India built by ISRO and fourth in the GSAT series. Its three GSAT predecessors were launched by GSLV during 2001, 2003 and 2004 respectively. After its commissioning, GSAT-4 will join the group of India's eleven operational geostationary satellites.

Some of the new Technologies being tested in GSAT-4 include:

- Electric Propulsion System
- Bus Management Unit
- 1553 Bus for Data Communication
- Miniaturised Dynamically Tuned Gyros
- 36 AH Lithium Ion Battery
- 70 V Bus for Ka band TWTAs

Besides, the Technology Experiments carried onboard GSAT-4 are:

On-board Structural Dynamics Experiment to monitor on-orbit structural dynamic behavior of the satellite during various phases of the mission corresponding to various flight/mission and satellite configurations

Velocity Measurement Package to measure the incremental velocity imparted to GSAT-4 during LAM firings and station keeping manoeuvres

Thermal Control Coating Experiment to study the degradation characteristics of thermal control materials in space environment with time

The cuboid shaped GSAT-4 has a lift-off weight of 2220 kg of which propellants weigh 1155 kg and the dry mass of the satellite is 1063 kg. GSAT-4 structure is based on ISRO's standard I-2000 bus. The two solar arrays (each with two panels) of GSAT-4 together generate about 2800 W of power.

GSAT-4 is the first geostationary satellite of ISRO to employ integrated Bus Management Unit (BMU) which combines the functions of Telemetry, Telecommand, Sensor Electronics and Control Electronics. BMU acts as the brain of GSAT-4.

Like its INSAT and GSAT predecessors, GSAT-4 has a conventional chemical propulsion system for orbit raising and station keeping manoeuvres. Besides, GSAT-4 is the first ISRO satellite having Electric Propulsion Sytem (EPS) to perform North South Station Keeping. The satellite will demonstrate the capabilities and advantages (very high Isp, meaning efficiency) of EPS employing state-of-the-art stationary plasma thrusters.

GSAT-4 at a glance:

Structure	: I-2000
Overall Size (m)	: 2.4 X 1.6 X 1.5
Liftoff mass (kg)	: 2220
Generated Power (W)	: 2760
Payload Power (W)	: 1785
Propulsion (Chemical)	: MMH as fuel and MON-3 as Oxidiser
Propulsion (Electric)	: Xenon based stationary plasma thrusters (four)
Mission Life	: > 7 years
Orbital Location	: 82 deg E longitude in GSO

GSAT-4 Payloads:

GSAT-4 carries communication as well as navigation payloads. They are:

- Ka - band bent pipe and regenerative transponder
- GAGAN payload operating in C, L1 and L5 bands

Of these, Ka-band Transponder operates on 30 GHz uplink and 20 GHz downlink. This payload provides 8 spot beams covering entire India. Spot beams allow frequency reuse through geographical separation. The payload also comprises beacon transmitters in 30 GHz and 20 GHz to facilitate propagation studies. Ka band payload also has the facility of RF tracking and antenna pointing.

New technologies incorporated in Ka-Band Payload include Multiple Spot Beams (eight) with Frequency Reuse, Double Frequency Conversion, Very High Stability Local Oscillator and Onboard Base band Processing and Switching.

The advantages of using a regenerative transponder are many. It allows the use of smaller ground terminals at the user end by incorporating efficient processing on-board the satellite. Regenerative transponder also increases system flexibility by facilitating network interconnection on-board satellite without the use of a hub, which in turn results in increased capacity, reduced errors and greater throughput.

Each of the 8 beams will have 8 narrow band channels of 64 Kbps and one wide band channel of 2048 Kbps. Interconnectivity between the narrow band channels within the same beam or with any of the other beams is possible.

Similarly, interconnectivity is possible with wide band channels between any of the beams or all beams can be used together in broadcast mode. Another objective of this payload is to develop advanced Digital Signal Processor based subsystems, implement various interface protocols and verify interconnectivity of terminals between multiple beams.

The intended applications for Ka band include Wide band Multimedia Services, Mobile Information System, SPACE LAN, e-Commerce and High Bandwidth Internet.

The second payload carried by GSAT-4 is GAGAN, which is a navigational payload operating in C, L1 and L5 bands. Essentially, the GAGAN payload of GSAT-4 forms the space segment of GAGAN Satellite Based Augmentation System (SBAS) developed by India. GAGAN stands for GPS Aided Geo Augmented Navigation. Through SBAS, the positional information from the GPS satellites is improved by a network of ground based receivers and the same is made available to any user through geostationary satellites.

GAGAN is a Wide Area Differential Global Positioning System (WADGPS) employing a geostationary satellite overlay system. It was conceived to provide a position accuracy of better than 7.6 metre needed for the precision landing of civilian aircraft. The GAGAN system consists of the Space Segment, the Ground Segment and the User Segment. The GPS and Geostationary overlay system form the Space Segment while the Ground Segment comprises Indian Reference Stations (INRES), Indian Master Control Centre (INMCC) and Indian Land Uplink Stations (INLUS). The User Segment consists of SBAS receivers capable of receiving GPS signals and corrections from the Geostationary satellite.

In the GAGAN architecture, Data from INRES is transmitted to INMCC. This data is processed by INMCC and sent to INLUS. INLUS transmits the corrected GPS information and time synchronisation signal to a geostationary satellite. The satellite then transmits a GPS like signal on L-band frequency. Accuracy of the order of 3 meter horizontal and 4 meter vertical is feasible in such a system.

Thus, GAGAN navigation payload of GSAT-4 receives the correction signals sent by Indian Land Uplink Stations in C-band and translates these into GPS L1 and L5 band signals and transmits these navigation signals. These signals can be received by GPS SBAS receivers, thus enabling them to get a highly accurate and reliable navigational fix.

The Technology Demonstration Phase(TDS) of GAGAN was successfully completed in August 2007. As part of the TDS, eight Indian Reference Stations (INRES) were installed at eight Indian airports. They are linked to the Indian Master Control Centre (INMCC) located at Kundanhalli near Bangalore. In June 2009, the final operational phase (FOP) of GAGAN was initiated.

Geostationary Satellites of India : Ushering in a Revolution

GSAT-4 is the nineteenth Indian geostationary satellite built by ISRO. In the past two and a half decades, India's geostationary satellites have revolutionised the country’s telecommunications, TV broadcasting and Weather Monitoring sectors. More recently, ISRO's INSAT and GSAT series of satellites circling the Earth in the 36,000 km high geostationary orbit have brought in a revolution in India's healthcare and educational sectors. Besides, they have been instrumental in taking the benefits of space technology directly to the doorsteps of rural India through Village Resource Centres (VRCs). Today, geostationary satellites are an integral part of India's national infrastructure. The country has about 200 communication transponders in geostationary orbit that operate in S, C, Extended C and Ku bands.

INSAT system has become a major catalyst for the expansion of television coverage in India. Satellite television (DTH) now covers 100% area and 100% population. The terrestrial coverage is over 65 percent of the Indian landmass and over 90 percent of the population. Around

30 million of TV Receive Only (TVRO) terminals were distributed and operational all over India by various DTH service providers.

Similarly, a total of about 650 Earth stations and nearly 120,000 VSAT terminals are operating in INSAT telecommunications network providing 9600 two-way speech circuits. Besides, Mobile Communication Services are also offered by the INSAT system.

Two of India's geostationary satellites - INSAT-3A and KALPANA-1 - are also providing meteorlogical services by sending weather imagery and relaying meteorological data collected by automatic Data Collection Platforms established in various parts of the country. At the same time, the Search and Rescue Transponder onboard INSAT-3A has picked up many distress signals and thus has enabled the saving of many lives through timely search and rescue operations.

India has a dedicated geostationary communication satellite called EDUSAT for educational field. Currently , about 52,000 classrooms from primary to university level as well as those in the non formal educational sector are in the EDUSAT network facilitating the extension of quality education to students in semi urban and rural areas.

Additionally, India's geostationary satellites have facilitated the extension of quality healthcare services to rural India. Presently, 306 remote/rural/district/medical college hospitals and 16 Mobile Telemedicine units are connected to 60 specialty hospitals in the ISRO telemedicine network.

This apart, as per the relatively recent Village Resource Centre (VRC) initiative, India's geostationary satellites have been instrumental in taking the benefits of space technology directly to the Indian villages by providing the much needed connectivity.

In this context, coupled with the growing demand for geostationary communication transponders, the launch of GSAT-4, which is a technology demonstrator for advanced satellite communications, acquires added significance.