Second developmental flight of Geosynchronous Satellite Launch Vehicle

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The successful orbiting of GSAT-2 spacecraft in the intended Geosynchronous Transfer Orbit by the second developmental flight of Geosynchronous Satellite Launch Vehicle, GSLV-D2, on 8 May 2003 has marked the entry of GSLV into operational arena for 2000 kg-class spacecraft. The second flight of GSLV, in addition to validating the design of the vehicle, has also demonstrated the enhanced payload capability by an additional 300 kg over the first flight through certain improvements implemented. Further flights will gradually augment the payload capability to about 2500 kg.

GEOSYNCHRONOUS Satellite Launch Vehicle, GSLV-D2 orbited the 1823 kg GSAT-2 precisely into the intended Geosynchronous Transfer Orbit (GTO) on 8 May 2003. GSLV is the fourth-generation launch vehicle developed by the Indian Space Research Organization (ISRO). Satellite Launch Vehicle (SLV-3; all-solid four-stage vehicle), and Augmented Satellite Launch Vehicle (ASLV; all-solid five-stage vehicle with strap-ons and closed-loop guidance technologies) were experimental vehicles. Polar Satellite Launch Vehicle (PSLV) employing both solid and liquid technologies has come to stay as the operational vehicle for launching national remote-sensing satellites. GSLV, a three-stage vehicle employs solid, liquid and cryogenic propulsion technologies. GSLV, after two successful developmental flights, is set to launch operational spacecraft. This article describes the GSLV-D2 mission with the technological changes incorporated. It also outlines future plans for upgrading the performance of the vehicle towards meeting the national requirements.

Vehicle configuration

GSLV, a three-stage vehicle is 49 m tall and weighs about 414 t at lift-off. The first stage (GS1) comprises a solid propellant motor (S139) and four liquid propellant strap-on motors (L40H). S139 stage is 20.1 m long and 2.8 m in diameter and it carries 138 t of hydroxyl terminated poly butadiene-based solid propellant; it is among the four large solid motors available in the world. The solid propellant motor develops about 4736 kN peak thrust and burns for 106.5 s.

The four liquid propellant strap-on (L40H) stages are 19.7 m long and 2.1 m in diameter. Each of them is filled with 42 t of hypergolic propellants UH25 and nitrogen tetroxide (N_2O_4). Each produces 765 kN thrust and burns for 149 s.

The second stage (GS2) of GSLV is 11.6 m long and 2.8 m in diameter. It is filled with 39 t of hypergolic propellants UH25 and N_2O_4. It produces a vacuum thrust of 804 kN and burns for about 135 s.

Figure 1. GSLV-D2 take-off.

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The third stage (GS3) of GSLV uses a Cryogenic Stage (CS) procured from Glavkosmos, Russia. The stage is 8.7 m long and 2.9 m in diameter and carries 12.6 t of liquid hydrogen and liquid oxygen. It burns for a duration of about 707 s, producing a nominal vacuum thrust of 73.6 kN.

The Payload Fairing, which is 7.8 m long and 3.4 m in diameter, protects the vehicle electronics and the spacecraft during its ascent through the atmosphere. It is jettisoned when the vehicle reaches an altitude of about 115 km.

Inter-stage structures, which connect different stages of GSLV, house the avionics and control systems. The vehicle equipment bay (EB) housing electronic systems like on-board processors, inertial navigation system, control electronics, guidance system, telemetry and telecommand system, etc. is mounted above the CS.

The spacecraft, which is mounted above the EB through a payload adapter, is separated by a Merman clamp-band joint and spring mechanism to provide the required separation velocity.

The three-axes attitude stabilization of the vehicle is achieved by autonomous control systems provided in each stage. Single-plane Engine Gimbal Control (EGC) of the four strap-ons is used for pitch, yaw and roll control. The second-stage engine has gimbal control system for pitch and yaw, and hot-gas Reaction Control System (RCS) for roll. For the third stage, two swivelable auxiliary cryogenic engines using GH2 and LOX with two-plane control provide pitch, yaw and roll control during thrusting phase and cold-gas system during coast phase.

Navigation, Guidance and Control (NGC) system in the EB located above the third stage manages the vehicle mission, from lift-off till spacecraft injection. A Redundant Strap-down Inertial Navigation System (RESINS) generates the state vector information. Digital autopilot (DAP), Guidance and Control Processors (GCPs) carry out control, guidance and sequencing functions. While DAP resident in on-board processor computes the control commands, the closed loop guidance scheme ensures optimum steering of the vehicle to reach the desired target conditions with the required accuracy at spacecraft injection.

For performance-monitoring, tracking, range safety/flight safety and Preliminary Orbit Determination (POD), the vehicle is provided with instrumentation using Pulse Code Modulation (PCM) telemetry transmitting in S-band frequency and radar transponders operating in C-band. During flight, the launch base-tracking radar system tracks the vehicle. Telemetry acquisition is done by the ground telemetry system at the launch base and Down Range stations located at Port Blair, Brunei and at Biak, Indonesia till the separation of the spacecraft from the launcher. The stage details are given in Table 1.

Technological changes

GSLV, from its earlier flight (GSLV-D1)[1], underwent certain significant improvements to upgrade its performance. The most significant improvement in the second flight was uprating the chamber pressure in all the five liquid engines. This necessitated analytical studies and experiments covering the feasibility, combustion-instability studies, parametric studies on engine performance, changes in propellant composition by adding hydrazine hydrate to unsymmetrical dimethyl hydrazine to enable stable combustion and qualification of indigenous silica phenolic throat for higher burn duration. In addition to stage evaluation firing tests the engine off nominal performance was verified for dispersion in chamber pressure and mixture ratio. The impact of the change with respect to transients, impact on checkout/clearance on launch pad and lift-off dynamics were also verified.

Another change was adoption of higher propellant loading (10 t extra) in the core solid motor. Such a motor has already been evaluated in the ground and PSLV flights. The effect of introducing this motor was extensively studied with respect to all mission interfaces. The Secondary Injection Thrust Vector Control (SITVC) system had been employed as a back-up to EGC of liquid strap-ons in the first flight.

Table 1. Stage details at a glance

Parameter	GS1 stage (first stage)		GS2 stage (second stage)	GS3 stage (third stage)
	S139 booster	L40H strap-on		
Length (m)	20.13	19.7	11.6	8.7
Diameter (m)	2.8	2.1	2.8	2.9
Propellant mass (t)	138	42	39	12.6
Case/tank material	M250 steel	Aluminium alloy	Aluminium alloy	Aluminium alloy
Propellant	HTPB	UH25 and N_2O_4	UH25 and N_2O_4	LH2 and LOX
Burn time (s)	106.5	149	135	707
Maximum vacuum thrust (kN)	4736	765	804	Nominal phase: 73.6
Control system		EGC single-plane gimballing for pitch, yaw and roll control	EGC two-plane gimballing for pitch and yaw control. Hot-gas RCS for roll control.	Two steering engines for thrust phase control and cold-gas RCS for coast phase control.

However, based on detailed analysis, simulations and the earlier flight experience, this system was removed in the second flight. This further enhanced the vehicle performance and improved the overall reliability of the vehicle. There has also been structural optimization in the payload adaptor and EB packages. All these changes put together resulted in an overall performance improvement of 300 kg payload from the earlier test flight GSLV-D1.

First flight experience

The first flight has demonstrated the use of the complex CS. The CS procured from Russia, was used as the third stage in the second flight also. The complex control, guidance and electronics for the CS have been designed, developed and implemented by ISRO. While the stage performance had been validated in the last flight, there was a shortfall in velocity of 60 m/s in the intended 5000 m/s provided by this stage. Subsequent to the flight, both Russian and ISRO teams had carried out detailed analysis of the performance of the stage. Various factors were studied, such as the measurement accuracies of flowmeters in the system, specific impulse targets and left-over propellant. After detailed analysis, extensive experimentation, exhaustive mission studies and analysis of the results of the ground qualification programme, sufficient margins in the CS performance were built in to ensure meeting the desired mission specification.

GSLV-D2 launch

For GSLV-D2 mission, the launch campaign commenced at Satish Dhawan Space Centre (SDSC), SHAR on 26 December 2002. The launch preparation started with the commencement of subassembly/stage preparations in the stage/subsystem preparation facilities at SHAR. The total activity at Mobile Service Tower for vehicle build-up and launch took about 69 days. The actual countdown commenced at T-39 h for launch on 8 May 2003. Some of the major countdown activities included filling up of earth-storable propellant for strap-ons stages and the second stage, completion of pyro-arming, movement of Mobile Service Tower and filling up of the cryogenic propellant, etc. Automatic countdown by the computer commenced at T – 10 min during which phase more than 500 parameters got checked out. The final countdown went smoothly, without any 'Hold'. The four liquid strap-ons were ignited at T – 4.8 s. After confirming that all the four engines attained the required thrust, the Launch Hold and Release Mechanism was withdrawn on command. The ignition of the core solid stage took place exactly at the opening of the launch window, as planned. The vehicle took-off majestically from the SDSC, SHAR launch base and after about 1013 s of flight, injected the GSAT-2 spacecraft into a GTO of 180.2 km × 36045.7 km at 19.25° inclination, once again demonstrating the country's capability for launching communication spacecrafts into GTO.

GSLV-D2 performance

From lift-off till injection of spacecraft, all the vehicle systems functioned normally. The vehicle followed the predicted flight path exactly as witnessed in the altitude and velocity profiles shown in Figure 2 *a* and *b*.

GS1 stage performance (liquid strap-on and solid core motor)

The four liquid strap-ons and solid core motor performed as predicted. The acceleration profile during GS1 phase is shown in Figure 3 *a*.

GS2 stage performance

The second stage, GS2, performed according to prediction and provided the required velocity till guidance issued a command to cut-off the stage on reaching the

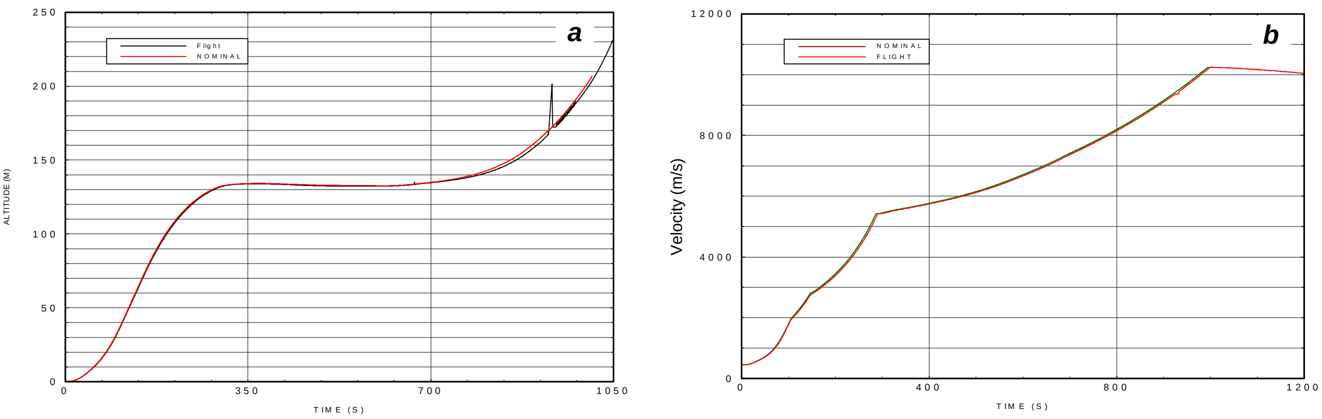

Figure 2. ***a***, Altitude profile; ***b***, Velocity profile.

specified target. The GS2 stage placed the CS along with the spacecraft into the targeted pillbox, as presented in Table 2. The acceleration profile during GS2 phase is shown in Figure 3 *b*.

CS performance

The CS burned for a duration of about 705 s and added an impulsive velocity of about another 5000 m/s, taking

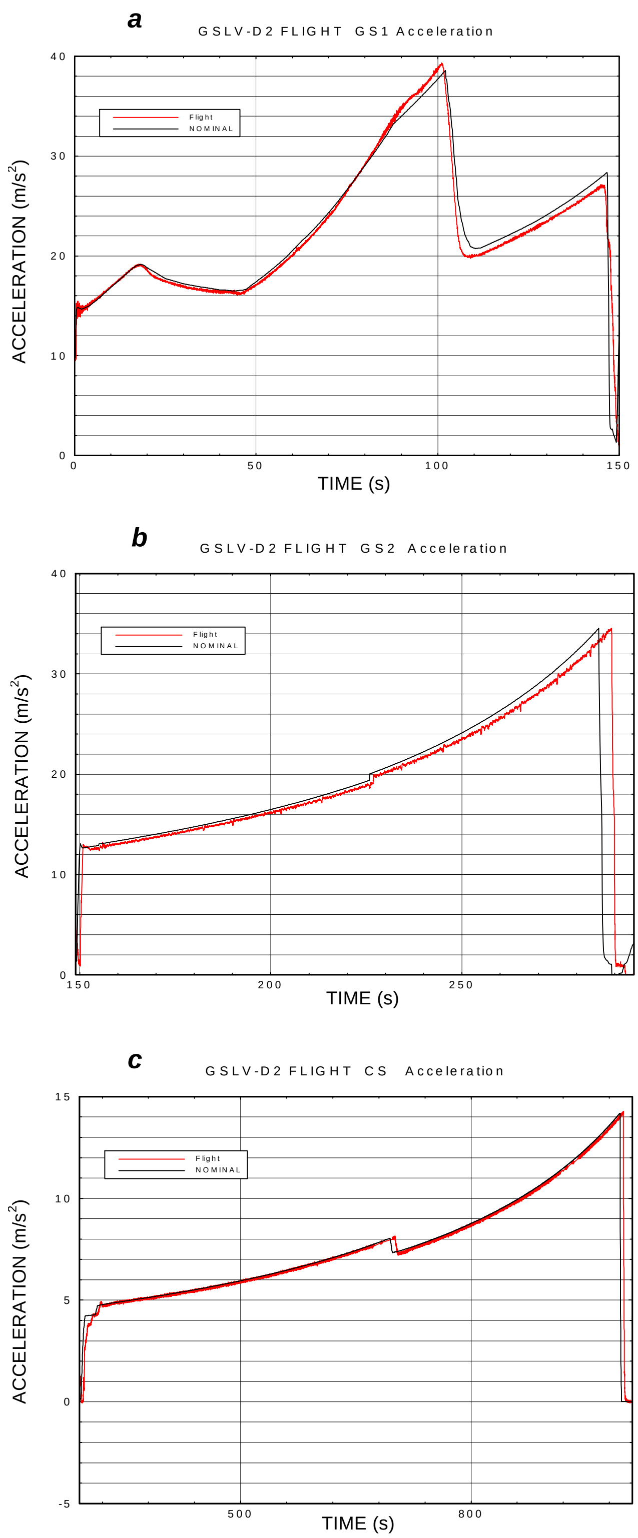

Figure 3. Acceleration profile during ***a***, GS1 phase; ***b***, GS2 phase, and ***c***, CS phase.

Table 2. Pillbox condition for CS

Parameter	Predicted	Achieved
Altitude (km)	131.4	131.4
Velocity (m/s)	5426.4	5422.3

Table 3. GTO injection parameters

Parameter	Specification	Achieved
Perigee (km)	180 ± 5	180.2
Apogee (km)	35975 ± 675	36045.7
Inclination (degree)	19.3 ± 0.1	19.25

the second spacecraft into GTO. The acceleration profile is shown in Figure 3 *c*.

The specification and flight achieved parameters in the injection conditions are given in Table 3.

GSAT-2 spacecraft performance

GSAT-2 was successfully injected into the GTO. Through a series of orbit-raising manoeuvres, the spacecraft was raised to geosynchronous altitude. Deployment of all systems, including the antenna reflector, solar array, etc. was successfully completed.

GSAT-2 is an 1823-kg class experimental communication spacecraft. It carries four C-band transponders, two Ku-bands transponders and a Mobile Satellite Service payload operating in S-band forward link and C-band return link. Besides the communication payloads, GSAT-2 also carries four piggyback experimental payloads, viz. Total Radiation Dose Monitor, Surface Charge Monitor, Solar X-ray Spectrometer and Coherent Radio Beacon Experiment. GSAT-2 measures 9.55 m in length in its final in-orbit configuration. It is a three-axis body stabilized using sun and earth sensors, momentum and reaction wheels, magnetic torquers and bipropellant thrusters. Its solar array generates 1380 W power, backed up by two 24 Ah Ni–Cd batteries.

Operational flights of GSLV

With two successful developmental launches, GSLV, in this configuration, is ready to carry operational spacecraft of 2000-kg class. The next flight of GSLV will carry EDUSAT, a dedicated spacecraft for education.

Indigenous cryogenic upper stage

The development of the indigenous cryogenic upper stage (CUS) has been taken up to replace the Russian-procured CS. Two engines have undergone a cumulative ground hot firing for nearly 4000 s in characterizing the engine performance parameters. Preparations are also going on for a stage qualification test planned during this year. The indigenous CUS is targeted for flight qualification during 2004–05. The indigenous CUS, with improved design of subsystems, provides a mass saving of nearly 300 kg over the existing CS procured from Russia.

Future upgrades

The payload capability of GSLV in its first flight (GSLV-D1) was 1540 kg. With planned improvements in the second test flight, its capability has been enhanced to 1823 kg. Also, by release of some conservative margins kept for the initial flights, optimization of systems and mass saving in procured CS, the capability of GSLV will be further improved to 2000 kg, and subsequently to 2250 kg using uprated CS. With the induction of indigenous CUS, GSLV payload capability will initially be 2200 kg and will be improved to 2450 kg with the uprated indigenous CUS. It may be noted from the above that the payload capability of GSLV is being enhanced systematically from 1540 kg to 2450 kg with planned improvements in a gradual manner in the coming years.

Conclusion

With the successful launching of GSAT-2 by the Second Developmental flight of GSLV (GSLV-D2) on 8 May 2003, a capability to launch 1823 kg in GTO has been demonstrated. With two successful test flights, the three-stage GSLV with CS procured from Russia is ready for carrying operational spacecraft.

1. Perumal, R. V. *et al*., First developmental flight of geosynchronous satellite launch vehicle (GSLV-D1). *Curr. Sci*., 2001, **81**, 167–174.

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