India’s first Polar Satellite IRS-P2 launched by PSLV-D2

On behalf of the scientific community, Current Science has great pleasure in congratulating every engineer, scientist and all (inside ISRO and outside) who participated (young and old) from top to bottom in this magnificent achievement.

Space history was made on 15 October 1994 when the second developmental flight of PSLV, PSLV-D2 successfully orbited IRS-P2 satellite into a precise polar orbit. The satellite was put on 3-axis stabilized mode within hours and the first photographs from the satellite were obtained the next day. Thus came to fruition, a totally indigenous vehicle-satellite-application mission of operational class. The orbit in which the PSLV-D2 has put IRS-P2 is so precise that only about 7.5 kg (equivalent to 15 m/s velocity) of fuel is required for final trimming of orbit compared to the provision of about 30 kg (equivalent to 60 m/s of velocity). The injection dispersions are comparable to that obtained with the operational Russian Vostok vehicle used for launching IRS-1A and 1B.

The performance of the vehicle is given in Figure 1 and Figure 2 which shows the textbook nature of the flight.

**PSLV at a glance**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lift-off weight (t)</td>
<td>283</td>
</tr>
<tr>
<td>Lift-off thrust (t)</td>
<td>450</td>
</tr>
<tr>
<td>Height (m)</td>
<td>44.2</td>
</tr>
<tr>
<td>No. of systems</td>
<td>100</td>
</tr>
<tr>
<td>No. of sub systems</td>
<td>390</td>
</tr>
<tr>
<td>No. of solid motors</td>
<td>24</td>
</tr>
<tr>
<td>No. of liquid motors</td>
<td>2</td>
</tr>
<tr>
<td>No. of control systems</td>
<td>9</td>
</tr>
<tr>
<td>No. of separation systems</td>
<td>14</td>
</tr>
<tr>
<td>No. of electronic packages</td>
<td>416</td>
</tr>
<tr>
<td>No. of electronic components</td>
<td>1,000,000</td>
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<tr>
<td>No. of electrical connectors</td>
<td>1500</td>
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<tr>
<td>Length of electrical wires (km)</td>
<td>120</td>
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<tr>
<td>No. of control components</td>
<td>170</td>
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<tr>
<td>No. of pyro components</td>
<td>170</td>
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<tr>
<td>No. of batteries</td>
<td>28</td>
</tr>
<tr>
<td>No. of sensors</td>
<td>525</td>
</tr>
<tr>
<td>No. of fasteners</td>
<td>2,70,000</td>
</tr>
</tbody>
</table>

**Mission objectives of PSLV-D2/IRS-P2**

The second developmental launch of the Polar Satellite Launch Vehicle, PSLV-D2, was aimed at demonstrating the capability for launching India’s IRS class of remote sensing satellites into polar sun-synchronous orbit.

The primary objective of IRS-P2 spacecraft mission is to provide a payload for the PSLV-D2. Further, using the flight opportunity provided by PSLV, it was planned to accommodate a Linear Imaging Self-Scanner, LISS-III, similar to that flown on IRS-1A and IRS-1B.

**PSLV-D1 flight**

The first developmental launch of PSLV, PSLV-D1, took place on 20 September 1993 from SHAR Centre, Sriharikota. Though not successful in placing the IRS-1E satellite on board, into the intended orbit due to a software implementation error, PSLV-D1 proved, in flight, all the
individual subsystems including the propulsion and control hardware separation and jettisoning, etc. PSLV-D1 also helped in validating the launch campaign procedure and the ground support systems. Further, the first two lower stages, which are planned to be used in India’s Geosynchronous Satellite Launch Vehicle (GSLV), were also proved during the PSLV-D1.

**PSLV-D1 Failure Analysis Committee (FAC), findings and recommendations**

A national level Failure Analysis Committee (FAC) chaired by N. Pant, Member, Space Commission, including experts from academic and R&D institutions in the country, besides ISRO, was constituted on 30 September 1993 and the committee submitted its report on 14 December 1993. The FAC has unambiguously given its findings on the causes of the failure.

The FAC has confirmed that the failure of PSLV-D1 to reach the intended orbit was primarily due to a software error in the pitch control loop of the onboard guidance and control processor, which occurs only when the control command exceeds the specified maximum limiting value. The above preset limit value was exceeded due to the disturbances experienced during transition between the second and third stages of the rocket. These disturbances were caused by the
The first imagery shows the Brahmaputra river in the Kamrup district of Assam and the area around it. The clouds and their shadows, evergreen forests and water bodies are also clearly seen.

programmed gimbal nulling of the second stage 3.7 seconds before the ignition of the third stage, leaving the disturbances during the above period of the second stage tail-off uncorrected and the failure of two small retro rockets leading to a contact between second and third stages, during the separation of the second stage. The FAC has further confirmed that in spite of the above disturbances, the PSLV rocket design is so rugged that it would have reached the intended orbit, but for the software error.

Based on the analysis of the extensive telemetry data from the flight, and the detailed studies and simulations, the FAC has confirmed that all the major systems which had been integrated in the PSLV, both hardware and software including the giant solid booster and the liquid propulsion systems flight tested for the first time, have worked as planned and that there are no lacunae in the design of the vehicle; PSLV-D1 would have achieved the intended orbit but for a minor deficiency.

The major recommendations of the FAC, consequently are:

(i) to rectify the software implementation error
(ii) to delay the nulling of the second stage by about 2.0 to 2.5 seconds.

The FAC has further added that the deficiencies noted and the modifications suggested are quite normal for the first few developmental flights of a large complex system like PSLV and ISRO should have no difficulty in operationalizing PSLV very soon.

PSLV-D2, the second developmental launch of PSLV, incorporates the modifications recommended by the Failure Analysis Committee.
The second imagery covering parts of Meghalaya plateau (south-west of Shillong) shows the Surma river basin of Bangladesh. The Shillong town can also be seen. The cloud patches and their shadows are clearly visible in the imagery. Major fractures can easily be identified. The areas inundated by the river and its tributaries and the rice crop areas are also identifiable.

Further, PSLV-D2 will also incorporate an on-board computer-based scheme to retarget the satellite injection orbit to take care of any under-performance of the lower propulsion stages to some extent.

For a description of PSLV please refer to earlier article in Current Science (1993, 65, 522).

**Work centres in ISRO**

With the Vikram Sarabhai Space Centre in Thiruvananthapuram acting as the lead-centre, major responsibilities for design and development of PSLV are shared by the Liquid Propulsion Systems Centre, also headquartered in Thiruvananthapuram and the SHAR Centre in Sriharikota. The ISRO Inertial Systems Unit, Thiruvananthapuram, has developed the navigation systems for PSLV. The ISRO Telemetry, Tracking and Command Network (ISTRAC) is responsible for the telemetry and tracking support to PSLV mission.

**Complexity of PSLV**

PSLV is an order of magnitude more complex vehicle compared to ASLV requiring gigantic facilities and new technologies as well as a large industrial backup which had to be specially geared. PSLV has 77 major subsystems and its
The third imagery covers part of south-eastern area of Bangladesh. The lush mangrove forests in the estuaries of Meghna river are very clearly visible in the imagery. The suspended sediments in the river are clearly visible. The imagery also brings out a few small recently formed islands off the coast of Bangladesh.

development programme called for setting up of facilities which can handle the large size subsystems, which because of space constraints in Thumba, have been located in the 200 acre new complex at Valiamala, close to Thumba.

Amongst the most difficult technological challenges was the development of maraging steel accomplished in conjunction with DMRL and MIDHANI. Even after the development of the basic material, more than a year's combined effort had to be spent in improving the fracture toughness of the maraging steel and its weldability.

Likewise setting up a beryllium machining facility in cooperation with the Department of Electronics and the Department of Atomic Energy was a major step in producing required beryllium mirrors and flexures for various optical, electro-optical and gyro units.

New sea level as well as high altitude test facilities had to be set up at Mahendragiri for qualifying both Vikas liquid engine and fourth stage liquid engine.

Large fabrication facilities to deal with 2.8–3.0 m rocket hardware, titanium machining and welding and massive mobile launch tower at SHAR had to be realized. High precision radars in C-Band have been built for tracking PSLV and are being positioned at SHAR, Car Nicobar and Mauritius.

Development of inertial platforms, large propellant casting and curing facilities to cast 125 tonne solid booster with five segments, development of segmented joints to avoid shuttle type failures, development of fourth stage high performance liquid engine all proved to be technological challenges.
PSLV first stage motor employing 129 tonnes of propellant within a 2.8 m diameter maraging steel motor case is a major leap from the SLV-3 motor with 10 tonnes propellant and 11 m diameter 15 CDV 6 motor cases. Six of these motors have performed normally in the D1 flight along with the core PSI motor.

The second stage of PSLV carrying 37.5 tonnes of propellant has gone through 1200 seconds cumulative firing prior to D1 flight and the engine is on regular production in industries.

Development of the high performance Kevlar third stage has been a daunting task. This motor using a submerged contour nozzle and flex nozzle went through two successful tests but failed in two consecutive tests. A series of corrective steps involving propulsion, structural, thermal aspects had to be taken and the motor has now been successfully qualified in six tests including the ones under vacuum ignition. The flight performance in D1 is normal.

The fourth stage uses indigenously developed twin liquid engines of 700 kg thrust each, has gone through 7500 seconds of cumulative firing including 330 seconds in vacuum test. In D1 flight the performance was normal till the telemetry data was available (about 100 sec).

The equipment bay of the vehicle accommodates the guidance and electronic subsystems including the Redundant Strap down Inertial Navigation System (RESINS). The qualification module of the system has been tested and the entire equipment bay has gone through functional and environmental tests using the specially designed checkout system, developed for PSLV.

Another major technical challenge during the development has been qualification of the interstage structures, with specially fabricated structural test set up.

The heat shield for PSLV uses isogrid structure machined by the special equipment procured for the purpose. All the aerospace mechanisms including heat shield jettisonning tests for PSLV have been completed.

The launch complex at Sriharikota is ready as is the mobile service tower 76 m tall employing 3000 tons of steel, perhaps the largest moving building in the country. MST has all the facilities to handle the rocket assembly, including an overhead crane of 60 tonne capacity and a clean room for spacecraft preparation and heat shield assembly.

National efforts

All these complex tasks have been completed because of the dedicated efforts of not only all ISRO/DOS centres but also a host of other institutes and over 150 industries, both in the public and private sectors. They are involved in the fabrication of a variety of hardware: light alloy structures for interstages, motor cases, electronic packages, heatshield, precision coherent radars, etc. Even in the field of chemicals and materials, the industries play a vital role; for example, the maraging steel and HTPB resin are produced by the industries.

They include DMRL, MIDHANI, NAL, HAL, BEL, various industries such as M/s L&T, WIL, BEML, BHEL, MTAR, GODREJ, VALCAN LAVAL, AURO Engineering, RKE, KCP, TANSI, SIDCO, KAL, KELTRON, HMT, PYN, NOCIL, HOC, Andhra Sugars, etc.

Cost of PSLV project

The PSLV project cost of Rs 414.96 crores includes the cost of two vehicles and all the remaining cost is for infrastructure development. The cost of single PSLV is only about Rs 45 crores. Almost all aspects of the technology have been validated by the first flight. The infrastructure already created will be useful for future PSLV launches as also for GSLV.