Indigenous Cryogenic Technology:
Implications for India's Space Programme

RS Thakur

From launching sounding rockets on the Kerala coast in the 1960s, to the launch of ten satellites in one go in April 2008, Indian space scientists have indeed come a long way. In fact, this January, taking one more crucial step in space technology has further strengthened their resolve to accomplish other space-related goals. After two decades of the protracted and focussed research and developmental efforts of the Indian Space Research Organisation (ISRO) scientists, it was India's turn to celebrate the glory of its space programme on January 05, 2014, when ISRO's Geosynchronous Satellite Launch Vehicle (GSLV-D5), powered by an indigenously developed cryogenic engine, successfully launched the GSAT-14, a communication satellite, from Sriharikota.

The cryogenic engine imparted a 36,000km/hr velocity to the launch vehicle, thereby putting the 1,982 kg communication satellite into a geosynchronous orbit of 36,000 km. India, thus, became the sixth country after the US, Japan, Russia, France and China to develop this highly complex technology. This successful launch with an indigenous cryogenic engine has further validated India's reputation as a 'silent

Brigadier **RS Thakur** is presently at the National Defence College, New Delhi.

N.B. The views expressed in this article are those of the author in his personal capacity and do not carry any official endorsement.

giant' in the global hierarchy of space-faring nations. The newly attained technological capability will now enable ISRO to launch communication satellites heavier than two tonnes into high Earth orbit as also undertake various deep space missions.

ISRO's Steady Progress in Rocket Technology

Recognising the importance of rocket technology in space applications, Dr Vikram A Sarabhai, a scientific visionary and the founding father of the Indian space programme, established the Thumba Equatorial Rocket Launching Station (TERLS) at Thumba, a village near Thiruvananthapuram, way back in 1963. Dr Sarabhai saw in space, a use which was very different from the military objectives of the US and USSR. He thought that for a developing nation like India, space offered many civilian, environmental and scientific solutions to its national needs. There was an international character to this first step in the establishment of a certain level of space capability and this was supported at that time by the US, USSR and France.

ISRO commenced the development of the solid fuelled Satellite LaunchVehicle-3 (SLV-3) in 1973 under the Project Director, Dr APJ Abdul Kalam. On July 18, 1980, with the launch of the 40 kg remote sensing satellite Rohini, India became the seventh country in the world to demonstrate its capability to launch a satellite and place it in orbit. This was followed up by the development of the Augmented Satellite Launch Vehicle (ASLV) in the late 1980s. Relentless efforts in rocket technology resulted in the first successful launch of the Polar Satellite Launch Vehicle (PSLV) in October 1994 which inserted the 870 kg Indian Remote Sensing (IRS) P2 satellite into a low Earth orbit at 825 km altitude. The PSLV is capable of launching a 1,600 kg payload into a 620 km polar orbit or up to 1,100 kg into geosynchronous transfer orbit. It came to be used regularly for launching remote sensing satellites. The PSLV also launched satellites of other nations, including Germany, South Korea and Belgium.

The stage was now set for ISRO to commence development of the next generation launch vehicle, the Geosynchronous Satellite Launch Vehicle (GSLV) and related technologies such as cryogenics to launch the 2,000-kg class of satellites into geosynchronous transfer orbit. As compared to the PSLV launches, the technology requirements of the GSLV engine are much more complex due to the need to launch heavier satellites into orbits which are 70 to 75 times farther than the low Earth orbits wherein lie the PSLV launched remote sensing satellites. The GSLV is a three-stage vehicle, the first and second stages of which use solid and liquid propellant respectively. The third and the uppermost stage uses cryogenic propellants. It may also be mentioned here that of all types of rocket propulsion, cryogenic technology is the most complex to develop. In the cryogenic engine, liquid oxygen at -1830C and liquid hydrogen at -2030C is mixed in the required pressure and proportion, and pumped into a combustion chamber using a turbo pump which runs at 40,000 rpm. A cryogenic rocket engine produces much more thrust for every kilogram of propellant burnt as compared with solid fuel.

The Initial Efforts

India's endeavour to develop fully indigenous cryogenic technology commenced in 1971 with the establishment of the Cryogenic Techniques Project (CTP), constituting a team of seven scientists. CTP did some useful work and provided inputs in 1973 for a 7.5 tonne-thrust fully cryogenic engine. However, subsequent to the passing away of Vikram Sarabhai, the first Chairman of ISRO, the CTP was closed down, thereby putting an end to the work by ISRO on cryogenics.

Between 1973 and 1987-88, ISRO focussed its attention on the development of the Viking engine technology, in collaboration with France, to be used to power the PSLV for inserting payloads up to 1,600 kg in the low Earth orbit. In that period, ISRO felt it prudent to continue its focus on building the PSLV based on a much surer technology such as the Viking engine instead of diverting resources on the development of a cryogenic engine. Because the payload ceiling of the Viking technology was much below the communication satellite, all the Indian National Satellites (INSAT) for communication had to be launched through the launch services of foreign agencies.

Emergence of Necessity

Notwithstanding the steps taken in the 1970s and early 1980s to develop cryogenic technology, during the latter half of the 1980s, ISRO, based on the experience of other space-faring nations, came to the conclusion that indigenous development of a cryogenic engine which would take about 15 years was less preferred than the import option which was likely to fructify in five to six years. India, therefore, approached the US, Japan and France to acquire the cryogenic technology. Both Japan and US declined to share their LE-5 engine and RL-10 engine technology respectively. France agreed to sell its HM-7 engine at a huge cost of Rs 1,000 crore, but the proposal was rejected by the Indian government due to the exorbitant cost.

The only option to import the technology was now from the Soviet Union. A Rs 235 crore contract was, therefore, signed between the Russian Space Agency, Glavkosmos and ISRO in January 1991 for the purchase of seven ready-made cryogenic engines along with technology transfer. However, the break-up of the Soviet Union in December 1991 and insistence by the US not to transfer cryogenic technology to India, jeopardised this agreement subsequently. Though the US cited the Missile Technology Control Regime (MTCR) guidelines as the reason for the denial of the technology, certain commercial considerations were also reportedly the cause of this decision. Bowing to the US pressure, Russia renegotiated the contract in 1992 wherein it agreed to provide seven cryogenic engines but without technology transfer. Having realised that India was unlikely to get this critical space technology from any of the space powers, ISRO decided to renew efforts to develop the same within the country.

The Development Saga

In 1990, the indigenous GSLV project, which included the development of a 12-tonne thrust fully indigenous cryogenic engine, was approved for a cost of Rs 756 crore. Simultaneously, India approached the Soviet Union to indigenise Russia's cryogenic technology, which had been developed by the Soviet Union with their first successful launch using a cryogenic engine in 1987. In 1993, as per the renegotiated contract between Glavkosmos and ISRO, seven flight-worthy stages were delivered to ISRO.

In 1995, ISRO constituted the Cryogenic Upper Stage (CUS) development project with the objective of indigenously realising a cryogenic stage with the same specifications, configurations and interfaces as the Russian cryogenic engine to sustain the GSLV flights after exhausting the Russian supplied cryogenic engines. The cryogenic engine was planned to be fabricated by the Indian industries based on the drawings generated from the documents received from the USSR during the initial phase of Indo-Russian interaction. The first development flight of the GSLV, using the Russian engine, on April 18, 2001, was a sub-optional launch due to the underperformance of the Russian cryogenic engine. This led to the insertion of the GSAT-1 satellite into an orbit which was much lower than the planned one. As a result, the GSAT-1 could not reach a stable orbit and its life was curtailed to only one year.

The indigenous cryogenic engine was developed at the Liquid Propulsion System Centre (LPSC), Mahendragiri, near Nagercoil in Tamil Nadu. During the period of about a decade between April 2001 and December 2010, seven GSLV flights were attempted. Four out of these were failures, three with Russian cryogenic engine stages and one with an Indian version. The developmental launch of the GSLV-Mk I on May 08, 2003, was a success which placed the 1,825-kg GSAT-2 satellite into orbit. This was followed by another successful operational launch, F01, on September 20, 2004, that led to the insertion of EDUSAT, a 1,950 kg satellite into orbit. ISRO's first attempt to launch the GSAT-4, using

Having crossed the cryogenic technology hurdle, India is now well poised to relentlessly pursue its multifaceted future space programme, including launch of heavier communication satellites, manned space missions and outer space missions to the Moon and Mars.

the GSLV-D3 powered by an indigenous cryogenic engine failed on April 15, 2010. . The next GSLV-D5 launch scheduled on August 19, 2013, from the Satish Dhawan Space Centre (SDSC) at Sriharikota was aborted at the last minute due to gas leakage from the propellant tank.

ISRO now carried out a comprehensive review of the previous seven GSLV flights through a committee of experts. This was followed up by holding a series of ground tests on the various sub-systems and the cryogenic engine at the LPSC after making the necessary changes in the design of the sub-components. ISRO took no chances this time and came up with a refurbished launch vehicle along with a new first stage, new second stage and a new strap-on motor which were used in the GSLV-D5 which successfully launched the GSAT 14 on January 05, 2014.

Future Plans

To exploit the successful launch of the GSLV-D5, ISRO has planned more GSLV launches using indigenous cryogenic engines. ISRO plans to progressively enhance the payloads to 2,250 kg and subsequently to 2,500 kg in the future flights. In 2015, the next GSLV launch is scheduled to carry the GSAT-6 into orbit. Subsequent GSLV launches will carry the GSAT-7A, GSAT-9, geo-imaging satellite and some more communication satellites of the two-tonne variety.

Meanwhile, ISRO is also working towards the development of a new version of the GSLV called GSLV-Mk III. The GSLV-Mk III is bigger and more powerful than the GSLV- Mk II and will have a totally indigenous 20-

tonne thrust engine with propellants weighing 25 tonnes. The entire vehicle will be 50 m tall and weigh 600 tonnes and will be capable of launching up to 4,000 kg payload into geosynchronous transfer orbit. Further, future plans also include the development of a launch system which will use two stages to orbit as against the existing three-stage launch system. Lastly, efforts by ISRO are also continuing to develop a reusable launch vehicle with a view to cut down the cost of access to space which is presently very high.

Implications for India's Space Programme

The development of indigenous cryogenic technology is indeed a 'historical breakthrough' for the Indian space programme for many reasons. Firstly, apart from issues of prestige, it implies that India has become a fully independent member of the global space community, wherein it no longer has to depend upon Europe's Ariane 5 to launch its heavier satellites into space. Secondly, it also improves the prospects of ISRO upgrading its rockets to launch manned space missions, once GSLV is certified 'Man Rated', that is, fit to carry astronauts into space. Thirdly, ISRO whose commercial wing Antrix Corporation is already a significant player in the commercial segment of space, is better placed to enter the lucrative market of providing heavy weight class of launch service via its GSLV, capable of lifting satellites and other payloads weighing four tonnes and more. Lastly, the indigenous cryogenic technology also provides India the capability to launch future missions to the Moon and Mars.

In the past two decades, the ISRO scientists have shown a great amount of grit and determination in accomplishing mastery over rocket technology. Development of an indigenised cryogenic engine and its validation in the successful launch of the GSAT 14 is indeed a major breakthrough for India. Having crossed the cryogenic technology hurdle, India is now well poised to relentlessly pursue its multifaceted future space programme, including launch of heavier communication satellites, manned space missions and outer space missions to the Moon and Mars.