India’s Firm Strides in Space

All photographs Courtesy: Mr D. P. Kaushik, Head P & PR, ISRO, Bangalore.

The launch of GSLV-D5 early this year, riding on an indigenous cryogenic engine, is a major milestone in India’s spectacular space programme.

On 5 January 2014, with the successful launch of the GSLV-D5, India’s space programme notched up yet another spectacular success. ISRO launched its modified GSLV-D5 having in its upper (third) stage the indigenous cryogenic engine. With this India joined the select club of six nations that have this technology. The other countries are USA, Russia, Japan, China and France.

During the past four years this is the first taste of success for GSLV (Geosynchronous Satellite Launch Vehicle). This was the eighth flight of the GSLV, out of which five have been partially successful while three failed totally.

GSLV-D5 took off from the Satish Dhawan Centre at Sriharikota at 4:18 pm on 5 January 2014. Everything went off in copybook fashion. After the brief 17-minute flight GSLV-D5 placed, by far the most sophisticated communication satellite, GSAT-14 in its geostationary orbit. This event was the culmination of the two-decade long diligence of ISRO scientists and engineers in the development of an indigenous cryogenic engine.

This success has ensured that we will no longer be dependent in the future on the launch pads of other nations for launching our heavy satellites. It will also save precious foreign exchange which will in turn speed up our space programme. This is a major advance in technology and will give us the capability of launching satellites of other countries too. We have done this before but it was limited to small mass satellites but now the doors of a vast multi-million dollar international satellite launch market have truly opened up for India.

The 49-metre high, 414-ton heavy rocket can presently only lift up to 2.5 ton satellites to geostationary orbits. This capability falls short of our own future requirements as well as those of the international market. In order to be truly competitive we will have to raise our competence level to 4-ton capability for launching satellites of INSAT-4 class. The good news is that ISRO had initiated efforts in this direction several years back.

Today, if we wish to send to space a communication satellite having mass greater than 2.5 ton, we have to depend upon the Guyana Space Centre located at Kourou in French Guyana, which is a joint facility of the ESA (European Space Agency) and French Space Agency and has the commercial name ArianeSpace. We have to shell out almost as much as Rs. 500 crores for this. But with our own GSLV this will cost us only about Rs. 200 crores per launch.

For this very reason, ISRO is working hard on the development of an advanced GSLV Mark-3 system that would be just 42.3 metres high but will weigh much more, 630 tons, and will be able to lift 4-ton mass satellites to geostationary orbits. In all probability, our next GSAT-6 communication satellite and Chandrayaan-2 may use this indigenous technology for launch and, hopefully, we may never have to rush our satellite payloads to Kourou in French Guyana.

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A Bit of History

No one can forget the successes of NASA (National Aeronautic & Space Administration of USA) with its Saturn V rocket. More importantly this was the workhorse for the famous Apollo missions that landed the men on moon by 7 Apollo missions (11 to 17 with the exception of 13 that failed). The last stage of the Saturn V rocket was a cryogenic engine.

Well, so the technology that NASA had built, tested and successfully used repeatedly 53 years back is the one we have developed now? That late? Viewed from this skewed perspective perhaps you may not rate ISRO's success with the cryogenic engine as anything great. But, we must also remember that during the last 20 years no other country could develop it except us. We do not know how many must have attempted it many times and failed. ISRO's success is indeed a big technology jump for our country and a truly laudable achievement.

The GSLV-D5 was slated to be launched on 19 August 2013 but a fuel leak detected at the right time forced it to abort. The system was immediately sent to the Vehicle Assembly Division for rectification of faults and within five months the malfunctioning parts were identified and the problem resolved. ISRO was quite chary and apprehensive this time. They took utmost care by conducting several ground tests and many design modifications were incorporated. Only then was the GSLV-D5 declared fit and flight worthy.

One of these modifications was the redesigning of the outer casing that creates a shell around the cryogenic upper stage and protects from extreme temperature that is produced due to friction with the atmosphere. The cable tunnel too, which carries the electrical wires to this section, was redesigned. It was strengthened to withstand the great g-forces at the time of launch.

The satellite that GSLV-D5 successfully launched into space, GSAT-14, is the 23rd geosynchronous communication satellite that India has put up. It has joined the other eight active communication satellites of India that are parked around 74 degrees east longitude. Close to it reside the INSAT-3C, INSAT-4CR, and Kalpana-1. GSAT-14 has 12 communication transponders that will
The result was the successful flight of this launch vehicle on 5 January 2014, work on which had begun just 10 months before. And this capped yet another saga in India’s highly successful space programme!

further augment our communication capabilities.

What is Cryogenic & Why is it so Indispensable?
The ISRO’s GSLV is a three-stage launch vehicle. Its lowest part or the first stage is a solid fuel propelled booster which has four strap-on smaller rockets attached to it for launch-time stabilisation and these use liquid propellants. Normally for solid fuel hydroxyl-terminated polybutadiene (HTPB) is used and sometimes it is used as a binder-cum-fuel HTPB 12% with 68% of ammonium perchlorate as oxidizer mixed with 20% aluminium powder, which also serves as fuel. The liquid fuel in the four strap-on boosters and also the second stage are usually the hypergolic propellants. These are generally the admixtures of dinitrogen tetroxide (N2O4) in combination with hydrazine (N2H4), monomethyl hydrazine or unsymmetrical dimethylhydrazine. And, the third stage is the cryogenic stage.

As young children, we learnt about escape velocity – if an object is thrown up with a speed of 11.3 km/sec or greater it would escape from the shackles of earth’s gravity and never come back again. Well, even if we had rockets capable of generating such huge thrusts they would never be used in actual practice to fly rockets for at such speed the atmospheric friction generated temperatures would be so intense that the rocket would burn quickly. Therein lies the answer to the question: Why multi-stage rockets are used? So that speed is low while the rocket is passing through the thick lower atmosphere and gradually increases after burn-off of the second and third stages so that correct speed is gained at the end that would place a satellite at the designated slot at the right speed.

When the third and final stage is fired it has the task of generating sufficient thrust to place in orbit a satellite having mass having 3 ton or more. Approximately, 6500 kN (kilo newton)
of thrust is required for this task. This cannot be achieved from either the solid or liquid propellants. What is required is a technology that would burn lot of lightweight fuel in very little time producing a great amount of hot exhaust gas that would give it forward thrust following the third law of motion.

It has been found that nothing can beat hydrogen and oxygen. Hydrogen is the lightest element and oxygen essential for combustion. Their burning does not leave any residue and only hot water vapour is the byproduct. If stored in gaseous form, which is their normal state at normal temperatures, we would require very cumbersome heavy cylinders and the very purpose of generating great thrust would be defeated. The solution is to keep these in liquid state whereby large quantities can be maintained in relatively small cylinders without burdening the weight of the stage.

This is an elegant solution but this is where you run into predicaments. The reasons are simple to understand. While oxygen liquefies below -183 degrees centigrade we have to go below -253 degrees centigrade (which is just 20 degrees higher than the lowest temperature the laws of physics allow us, the absolute zero, or -273 degrees centigrade) in order to bring hydrogen to liquid state.

In physics, cryogenics is the science of production of very low temperatures (below -150 degrees C) and the study of the behaviour of materials at those temperatures.

The Challenges

It is possible to produce such low temperatures in the laboratory and also store these liquefied gases. But using them for rocketry is another ballgame. You have to keep the two constituents at two different temperatures and then route them through pumps to the combustion chamber. This is a big technological challenge.

The easier option before ISRO was to import this technology and then develop it in its labs. It turned out to be a big problem. Amongst the ‘haves’, the US, Japan and France either said a total ‘no’ or offered the rockets at exorbitant prices. We then turned to our unwavering trusted friend Russia, the third country to develop this technology.

The US was the first to demonstrate this technology in 1961, then came Japan in 1977 and then Russia in 1987. Notice the time intervals! Russia has had many firsts in space. It was not only the first country that put a satellite into space (1957) but also sent the first man in space as early as 1961. Yet, it took this long for Russia to develop the cryogenic technology – 26 years after US!

Since that time India tried its best to import this technology from Russia. We were trying to acquire a technology from Russia that was not successfully tested by them and they had put it into cold storage after four repeated failures. There were murmur of protest within ISRO but they went ahead and a deal was struck.

In 1991, Russia agreed to give us two cryogenic engines as well as the technology at a low price. Russia was at that time embroiled with its own internal problems and this deal was a good financial proposition for them in their difficult times. But it did not work out for us. America played the spoilsport. They put pressure on Russia that this would escalate the nuclear arms race in Asia. Who would dare tell America that nuclear missiles do not use any cryogenic stage?
You do not take your warheads up into the stratosphere!

Under this extreme pressure Russia reneged on the deal, they had received the contract in 1992 which was after the breakup of the USSR. Once again we were rendered helpless.

**Indigenous Cryogenic Technology**

It all began in 1987 with the efforts of V. Gnanagandhi, the head of ISRO's cryogenic cell. A high-pressure hydrogen production plant was conceptualised in Mahendragiri near Thiruvananthapuram. We did not have any expertise in this area and importing the technology was the only alternative. No country was willing to transfer this safely guarded secret.

Negotiations started with several countries particularly with France. But after several rounds of talks we were back to square one. Yet, these failed negotiations taught ISRO a few things —

*Today, if we wish to send to space a communication satellite having mass greater than 2.5 ton, we have to depend upon the Guayna Space Centre located at Kourou in French Guayana, which is a joint facility of the ESA and French Space Agency and has the commercial name Arianespace.*

the difficulties involved in the production, storage and handling of liquid hydrogen and the precautions that are necessary.

Gnanagandhi’s team faced lots of teething troubles. Initially, they had no idea how to produce the two combustibles in liquid phase let alone using them in a rocket engine. When finally they did, the nozzles of the storage chambers needed to be cleaned and they used liquid nitrogen for this task but at the temperature of liquid oxygen, nitrogen becomes solid and this clogged the nozzles. But Gnanagandhi’s team did not give up.

In 1988, they developed a one-ton prototype cryogenic rocket, but unfortunately it blew up during the test. At that point, Dr. U.R. Rao, who was the head of ISRO, succeeded in convincing, after long discussions, the Russians into agreeing to sell us two cryogenic engines. The Russians were however not willing to part with the technology due to American pressure. Rao negotiated for at least eight engines if no technology transfer was done.

The Russians almost acquiesced and but finally gave only seven engines. Now, the problem was what to do with these engines. ISRO engineers did not know how to integrate these engines into their plans which even the Russians had not tested. There was no help coming from any quarter. The design of these engines was also very difficult to copy. We had to do everything ourselves.

In the year 1994, the government of India sanctioned a budget of Rupees 300 crore for the indigenous development of the cryogenic engine. ISRO as per its past practice partnered with domestic industry for this development and with the help of Godrej and MTR Technolgies they first set up a rotary vacuum brazing plant in Mumbai. This is a technique by which two metals are finely joined together. It took almost a year to set it up. Later, these two industries also produced several other equipments for ISRO.
FEATURE ARTICLE

ADVANTAGES OF CRYOGENIC TECHNIQUE

High efficiency per unit of fuel
Oxygen and hydrogen in liquid form give very high amounts of energy per unit mass due to which the amount of fuel to be carried aboard the rockets decreases.

Clean Energy
Hydrogen and oxygen are extremely clean fuels for only steam (water) evolves when their combustion takes place. This steam ejects from a nozzle and gives the rocket the forward thrust. In a manner of speaking a cryogenic engine is a high burning steam engine!

Very Economical (& indispensable for third stage)
Liquid oxygen costs less than petrol that we use in our cars. Thus hydrogen and oxygen combination is quite cost effective.

The Whys & Wherefores

If we focus our attention to a few important facts we can realize the onerous nature of the task of producing a basic cryogenic engine. As we have already learnt, the liquid hydrogen is stored at a temperature below -253 degrees centigrade but the electromechanical pump that is used to pump it to the combustion chamber operates at a temperature of 500 degrees centigrade and rotates 40,000 times per minute!

The temperatures produced in the combustion chamber are of the order of 3,000 degree centigrade. Such vast temperature differences in such a small engine! Moreover, the pressure inside the combustion chamber is about sixty times the normal atmospheric pressure. The walls of the combustion chamber have to be made strong enough to withstand such high pressure. Do we know any material (metal) that can remain solid at 3,000 degree centigrade? Not really (except Tantalum & Tungsten). Therefore, the walls of the combustion chamber have to be cooled continually.

In the year 2000, team ISRO made its first 7.5-ton engine. Unfortunately, during its test the hydrogen valve decided to close a wee bit early and this misbalanced the fuel mixture ratio that became explosive and the engine burst into flames.

Ultimately success was achieved in 2002 and by 2003 the technology had been perfected and was declared fit and space worthy. But our own cryogenic engine was not yet ready and this time too we had to use a Russian one. It took another four years before it could be made compatible with the requirements of the GSLV and integrated with it as the final upper stage.

The D-day had arrived, the date was 25 December 2010. The GSLV F-06 was ready to launch with the Russian cryogenic upper stage with the sophisticated communication satellite GSAT-5P as the reputable payload. In less than a minute of firing, the engine stopped functioning and once again it turned out to be a miserable failure. The ISRO website said:

“The performance of the GSLV-F06 flight of December 25, 2010 (with GSAT-5P Satellite onboard) was normal up to 47.5 seconds from lift-off. The events leading to the failure got initiated at 47.8 seconds after lift-off. Soon, the vehicle started developing larger errors in its orientation leading to build-up of higher angle of attack and higher structural loads and consequently vehicle broke up at 53.8 seconds from lift-off (as seen visually as well as from the Radars).”

“As per the Range Safety Norms, a destruct command was issued from the ground at 64 seconds after lift-off. The flight was hence terminated in the regime of the First Stage itself.”

“Soon after this, Dr. Radhakrishnan, the Chairman ISRO constituted a Preliminary Failure Analysis Team ……….”

A system designed and assembled to perfection with years of toil but that used a Russian cryogenic stage not only failed but also wiped out the costly payload, the GSAT-5P satellite. As per ISRO’s investigations it was not the cryogenic stage that failed the mission this time but “the cause of the failure is the untimely and inadvertent snapping of a group of 10 connectors located at the bottom portion of the Russian Cryogenic Stage”, the ISRO website states.

These were very frustrating times for ISRO. But ISRO did not give up. Our dependence on Russian cryogenic engines had to go. We had to develop our own engine. Following the findings and recommendations of the expert panel of Programme Review and Strategy Committee they set up in Mahendragiri in the district Tirunelveli of Tamilnadu a plant for the development of the indigenous cryogenic engine – a vacuum testing facility. Every system that failed earlier and could possibly fail in future was reviewed.

By the year 2013, almost everything was reviewed and work on the GSLV D-5 began at a frenetic pace. The result was the successful flight of this launch vehicle on 5 January 2014, work on which had begun just 10 months before. And this capped yet another saga in India’s highly successful space programme!

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