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WHY RESTART OF THE PSLV C-29 DURING LAUNCH OF SIX SINGAPOREAN SATELLITES IS A BIG DEAL

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On December 16, 2015, ISRO's Polar Satellite Launch Vehicle (PSLV)-C29 successfully launched six satellites of Singapore, including the 400 kg TeLEOS-1, the primary satellite, which is Singapore's first remote sensing satellite. The other five satellites were co. passenger payloads. Put together, the overall weight of the satellites on lift-off was 624 kg. All the six payloads were successfully placed into an orbit of 549 km height inclined at an angle of 15° to the equator. The satellites were launched one after another, 30 seconds apart, to avoid collision and set a distance of about 20 kilometres between them.

The successful placement re-emphasised and demonstrated to the world the PSLV's credentials both in terms of reliability as also cost. With regards to reliability, this was the 57th successful satellite for customers from abroad and consequently, the PSLV reliability rate stands at 100% in the international market. With regards to launch costs-at 26 million Euros or 30 million dollars[1], it is also by far the cheapest in the market.

With regards to the commercial aspect, these six satellites were launched as part of the agreement entered into between ST Electronics (Satcom & Sensor Systems), Singapore and Antrix Corporation Limited, the commercial arm of the Indian Space Research Organisation (ISRO), a government of India Company under the Department of Space (DOS). In commercial terms, as per India's Science and Technology Minister Jitendra Singh, India has earned about USD 100 million launching 45 foreign satellites till date and revenue from its commercial space missions is poised to grow with another 28 foreign satellites planned to be put into orbit between 2015 and 2017[2].

In addition to the above aspects that were well covered by the press, ISRO emphasised the part related to successfully switching on and off the rocket's fourth stage/engine 46 minutes after it delivered the satellites in space. The above operation is significant in many more ways than one and this paper attempts to explore the significance of the same. The context however is confined to a simplistic rendition of how the event has the potential to change the form lines of India's space capabilities.

Exploring the Significance of the Launch

To begin with, the PSLV is the venerable work-horse of ISRO. It is a medium lift launcher that can reach a variety of orbits including Low Earth Orbit, Polar Sun Synchronous Orbit and Geosynchronous Transfer Orbit. The PSLV has been in service for over twenty years and has launched various satellites for historic missions like Chandrayaan-1, Mars Orbiter Mission, Space Capsule Recovery Experiment, Indian Regional Navigation Satellite System (IRNSS) etc. Given below is a brief description of the vehicle.

Table-1: Brief Description of PSLV

Type	PSLV
Versions	Regular, Core Alone, XL
Height	44.5m
Diameter	2.8m
Launch Mass	229,000kg (CA) to 320,000kg (XL)
Mass to LEO	3,250kg
Mass to GTO	1,410kg
Mass to SSO	1,600kg – XL: 1,800kg – CA: 1,100kg

The vehicle can fly in three different configurations to adjust for mission requirements. The standard PSLV uses six PS0M strap-ons, powered by S-9 solid rocket motors; the smaller CA or Core Alone configuration flies without boosters and the heavier PSLV-XL makes use of six PS0M-XL units with S-12 solid motors. The vehicle configuration used in this particular case was the PSLV (CA) model that premiered on 23 April 2007. The CA model is used for smaller payloads and does not include the six strap-on boosters used by the PSLV standard variant. Going beyond the configuration, with regards to the rocket stages or engines, the PSLV is a four-stage rocket that uses a combination of solid and liquid fuelled rocket stages. The first stage is solid-fuelled, the second stage is liquid fuelled, the third stage is again solid fuelled and the fourth stage is liquid fuelled. In case of the launch in question, the Core Alone (CA) configuration has been used[3].

Solid and Liquid Engines and its effect on Restart in Outer Space

To successfully orbit, an injection velocity of 9500 m/s is required. So, the first stage or engine has to be a very powerful solid stage that has high propellant density and can produce high thrust to successfully put the payload into orbit. However, though solid rockets have high thrust they have lower specific impulse and hence burn out very fast. On the contrary, liquid propellants have higher specific impulse and last longer but produce lower thrust. Metaphorically speaking, a solid stage is like a twig stove and a liquid stage is like a gas stove. The twig can't be switched on and off at will, whereas the gas stove is like a tap that can be switched on and off, manipulated at will. Changing orbits in outer space is a great challenge and the acme of skill lies in the ability to switch on, off and manipulate at will. The same was demonstrated in this particular launch. The test will enable ISRO to develop rockets that can launch orbits at different orbits in one flight.

Going by press reports, just over 18 minutes into flight, the PSLV C-29 (CA) rocket ejected the TeLEOS and thereafter the other five satellites[4]. In around 21 minutes, all six satellites were put into their intended orbits at 550 km altitude. The fourth stage was then shut off and the vehicle was coasting thereafter for around 50 minutes. The fourth stage was then restarted again for some more time. Restarting a rocket engine soon after it shuts off in space is a critical technology that has to be mastered. Once a rocket engine is activated, the heat generated is very high and the mastery lies in cooling it down in space and restarting it within a short while. ISRO demonstrated precisely that with the above launch.

The Distinguishing Factors

In outer space, with the engines cut off, there is a total lack of any force acting on the rocket and hence it slows down until it comes to a complete stop in a particular orbit. The rocket no longer has to contend with Earth's gravity and hence keeps coasting at the same speed and in the same direction. Once the engines are restarted, the rocket again accelerates and goes into another orbit. It can stay in this orbit, deliver payloads, do experiments etc and thereafter go into another orbit for similar or other tasks. Simply put, the same vehicle now has the capability to not only place multiple payloads into a particular orbital plane but can place them in many more orbital planes. This is significantly different from normal station-keeping that is primarily an exercise in manoeuvrability to keep a satellite in its intended positional slot. The orbit in this case does not change as in case of most communication satellites that are placed in the Geo-Stationery Orbit at 35, 786 kms altitude. It is also entirely different from switching on and off a communication satellite's engines in space. The interval between two restarts of a communication satellite engine is in days. But in the case of restarting a rocket engine in low earth orbit, the time gap will be in hours.

It doesn't take much fuel to change position within the same orbital plane; however, to go to a different orbital plane a vast amount of fuel is required. For instance, satellites once jettisoned onto a particular plane may use their on-board propulsion to speed up and go higher or lower (as in case of the TES satellite). However changing direction would entail using up a lot of fuel and the useful life of the satellite would reduce significantly. Thus, one would normally need multiple launches to place satellites in multiple planes and different orbits. The above is particularly so in case of Global Positioning System (GPS) satellites that uses multiple satellites in multiple orbits. For instance, the US's NAVSTAR GPS has four satellites in six different orbital planes; Russia's GLONASS GPS has eight satellites in three orbital planes etc. Thus, for applications that require a regional or global coverage, the requirement would be for multiple satellites to be in different planes and launch vehicles like the PSLV C-29 enables precisely that and much more. Having a fourth stage, capable of restart makes things both efficient and economical at the same time. It multiplies ISRO's space capabilities, and by extension the nation's capabilities manifold. The test to restart the fourth stage of the PSLV rocket will help India in its future launches especially while attempting to launch multiple satellites in different orbits.

Conclusion

The launch experiment presents a variety of options for efficient launch and use of multiple satellites in a single attempt. It has a variety of spin-offs ranging from commercial gain to redundancy. Seen in the light of the prevailing advances and surge in the launch of small satellites, the potential for gain is enormous. With regards to commercial gain, satellite launch is a major expenditure in most satellite programmes and in some cases equals or even exceeds the payload costs. Technological maturing of engine restart capability multiplies efficiency by optimally using the launch and payloads in a single stroke. A single launcher placing several satellites on orbit saves time and money. The economies of scale gained by launching several payloads from a single launch vehicle create a huge bouquet of opportunities for India in general and ISRO in particular. With regards to redundancy, it enhances the rapid response or launch on demand capability of the country and enables rapid replenishment in case of operational gaps in capability and other requirements. Least of all, it reduces the incentive for adversaries to take out satellites in a particular orbit since other usable orbits are readily accessible now can be used for operations, especially in the context of satellites in low and medium earth orbits. The above listing of the potential of PSLV for multiple satellite launches in multiple orbits is but nothing more than a broad-brush of the possibilities and potential. A vast vista of opportunities unfolds and India should feel justifiably proud of ISRO's achievement.

(Disclaimer: The views and opinions expressed in this article are those of the author and do not necessarily reflect the position of the Centre for Air Power Studies [CAPS])

Notes

[1] Cost estimates are based on statement of India's Science Minister Jitendra Singh to the Indian Parliament. See Dennis S Jesudasan, "ISRO launches six Singapore Satellites" 17 Dec 2015 at http://www.thehindu.com/sci-tech/science/isro-launches-6-singapore-satellites/article7997165.ece accessed on 21 Dec 2015.

[2] Ref IBC News Bureau, "Jitendra Singh – India earned about US $ 100 million launching 45 foreign satellites"IBC News, 23 Jul 2015 at

http://www.ibcnews.in/2015/07/23/jitendra-singh-india-earned-about-us-dollar-100-million-launching-45-foreign-satellites/ accessed on 21 Dec 2015.

[3] For a more complete description of the PSLV, see site of Government of India, Department of Space, "Polar Satellite Launch Vehicle" at http://www.isro.gov.in/launchers/pslv and Spaceflight 101.com, "PSLV Launch Vehicle", 21 Dec 2015 at http://spaceflight101.com/spacerockets/pslv/ accessed on 22 Dec 2015.

[4] RefSee Dennis S Jesudasan, "ISRO launches six Singapore Satellites" 17 Dec 2015, *The Hindu* at http://www.thehindu.com/sci-tech/science/isro-launches-6-singapore-satellites/article7997165.ece accessed on 21 Dec 2015 and Press Trust of India report, "India launches six Singapore satellites on board PSLV C-29", 16 Dec 2015, *The Economic Times* at http://articles.economictimes.indiatimes.com/2015-12-16/news/69090711_1_isro-chairman-satellites-isro-scientists accessed on 22 Dec 2015.