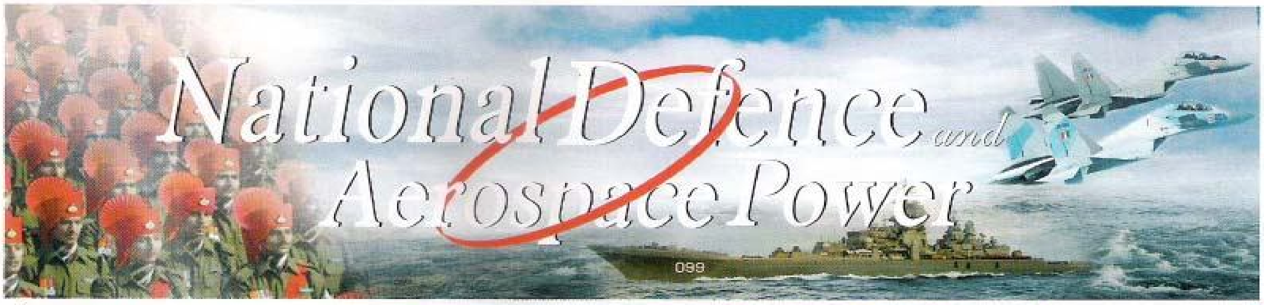

Centre for Air Power Studies ISSUE BRIEF

111 / 15 **29 December 2015**

Why Restart Of The PSLV C-29 During Launch Of Six Singapore 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 percent in the international market. With regards to launch cost, it is 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 brief 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	229,000 kg (CA) to 320,000 kg (XL)
Mass to LEO	3,250 kg
Mass to GTO	1,410 kg
Mass to SSO	1,600 kg – XL: 1,800 kg – CA: 1,100 kg

The vehicle can fly in three different versions 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 April 23, 2007. The CA model is used for smaller payloads and does not include the six strap-on boosters used by the PSLV standard variant.[3] Going beyond the versions, 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. The PSLV's four stage propulsive configuration provides a lot of mission flexibility. It enables longer flight durations between lift-off and the last stage of injection of space craft into orbit, thereby enabling a variety of activities in the final stages. Flight durations can be increased by allowing a long coasting between the burn out of the third stage (PS3) and the ignition of the fourth stage. The PSLV is the only launch vehicle of ISRO having this feature of coasting feasibility in the upper stage. It was this feature of flexibility that enabled the success of the Mars mission.

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In case of the launch in question, the Core Alone (CA) configuration has been used. The fourth stage is the one that is in news and hence a brief description of the fourth stage would enrich our understanding. The PS4 is the fourth and final stage of PSLV. This stage is responsible for the correct injection of PSLV's payloads into their respective desired orbits. The Upper Stage of the PSLV launcher is liquid fuelled using Monomethylhydrazine fuel and Mixed Oxides of Nitrogen as an oxidizer. The stage is 2.02 meters in diameter and has a length of 2.60 meters with an empty mass of 920 Kilograms. It contains 2,000 kgs of propellant when flying on the regular and XL configuration and 1,600 kgs when flying atop the CA configuration. The fourth stage is powered by two L-2-5 engines, each producing a thrust of 7.4kN and a specific impulse of 309 sec. The engines can be gimballed by up to 3 degrees for pitch and yaw control while roll control is provided by the Reaction Control System (RCS). The RCS is also used during coast periods and to re-orient the vehicle for spacecraft separation. The fourth stage has a variable burn time depending on the mission profile. It can support burns of up to nine minutes. The fourth stage also houses the Equipment Bay of the vehicle containing the inertial guidance system and flight computer (Vikram 1601) as well as telemetry and avionics equipment.

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. In case of solid fuel rockets, thrust cannot be controlled. Once lit, it burns at a steady rate. The rate of burn cannot be changed without changing the fuel composition. Once ignited, the engine cannot be switched on and off. On the contrary, in case of liquid fuel configurations, the thrust can be controlled and the engines can even be shut down and restarted at a later stage. In addition the energy density (Joules per kg of propellant) tends to be high resulting in high combustion temperatures and consequently specific impulse (impulse [in Newton seconds] per kg of propellant) is very large. Thus, the advantage is liquid propellants have higher specific impulse and last longer but produce lower thrust. A lower thrust suffices once the space vehicle is in the upper atmosphere or lower fringes of outer space. Metaphorically speaking, a solid stage is like a twig stove and a liquid stage is like a gas stove. The twig cannot 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. Mixing the competencies of both provides enormous flexibility and to make the picture clearer, a brief comparison of the first stage and last stage configuration is given below.

COMPARISON OF 1ST AND 4TH STAGE OF PSLV		
Parameters	**1st Stage/Engine**	**4th Stage/Engine**
Fuel/Propellant	Solid (Hydroxyl Terminated Poly Butadine/ HTPB)	Liquid (Mono Methyl Hydrazine)
Fuel Mass	9000 kg	2000 kg
Thrust	502.6 KN	14.6 KN
Impulse	262 secs	308 secs
Burn Time	44 secs	525 secs
Length	10 mtr	2.60 mtr
Diameter	1.0 mtr	2.02 mtr

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 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 the same in the above-mentioned 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. The details related to thermal management of the fourth PS4 stage have not been made public. However, the fact that the rocket engines were activated, switched off, cooled and then reactivated within minutes indicates a very high level of competency in thermal analysis and management of systems in outer space.

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On the other hand, it does not 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 the case of Global Positioning System (GPS) satellites that use multiple satellites in multiple orbits. For instance, the US 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 and medium 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 to deliver many payloads in many orbits at a single stroke. A single launcher placing several satellites on orbit saves time and money. Apart from single satellites, a variety of constellation configurations of small and even medium satellites can be formulated and placed in a single launch. The economies of scale gained by launching several

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payloads from a single launch vehicle create a huge bouquet of opportunities for India in general and ISRO in particular. The commercial spin-offs are significantly high. 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 and can be used for operations, especially in the context of satellites in low and medium earth orbits. Simply put, it is possible to populate many more orbits with required space craft at the same time and hence the targeting complexities for the adversary increase manifold. Even in case of successful targeting in any one orbit, there would be assets available in other orbits. There exist a variety of options and 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.

Notes:

[1] Cost estimates are based on statement of India's Science Minister Jitendra Singh to the Indian Parliament. For more details, see Dennis S. Jesudasan, "ISRO Launches Six Singapore Satellites", *The Hindu,* December 17, 2015, http://www.thehindu.com/sci-tech/science/isro- launches-6-singapore-satellites/article7997165.ece, accessed on December 21, 2015.

[2] "Jitendra Singh – India Earned About US $ 100 Million Launching 45 Foreign Satellites", *IBC News*, July 23, 2015, http://www.ibcnews.in/2015/07/23/jitendra-singh-india-earned-about-us-dollar-100-million-launching-45-foreign-satellites/, accessed on December 21, 2015.

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

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

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