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ISRO: 104 Satellites in 1 go

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ABSTRACT

On February 15, 2017, ISRO set a new world record by launching 104 satellites in a single PSLV-C37 mission. There are many records in this mission. The record countdown time of 28 hours, cost of the launch, time taken for ejecting 104 satellites without collision, engineering innovation, flaw less project management are some of them. The case study describes the ISRO's Journey, track record, vision, PSLV-C37 project, time management, cost management of the project, ISRO Jugaad, and their future plans of manned space missions, Reusable Launch Vehicles (RLV), moon lander, Mars, Venus and Jupiter missions. The case study also highlights ISRO becoming destination for foreign companies for commercial space services at low cost.

Keywords: Project Management, Project Time Management, Project Cost Management, Jugaad, Project Planning, Project Execution, Reuse.

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"Congratulations to @isro for the successful launch of PSLV-C37 and CARTOSAT satellite together with 103 nano satellites!"¹.

----- Honourable Prime Minister of India, Narendra Modi
On Twitter (February 15, 2017)

"We (Indian Space Research Organization) started with ten satellites (on board a single rocket), then went to 18 or something; then it's 35. Now it's 100. If you make 3 or 4 kg satellite, it (PSLV) can take 300 to 400 satellites at a time"².

----- G. Madhavan Nair, Former ISRO Chairman
The Economic Times (February 15, 2017)

INTRODUCTION

In 1962, Government of India decided to go to space and setup National Committee for Space Research (INCOSPAR). Under the leadership of visionary Dr. Vikram Sarabhai, INCOSPAR setup Thumba Equatorial Rocket Launching Station (TERLS) at Thiruvananthapuram, Kerala, India in 1962 with UN Sponsorship. With the identification of importance of space technology in nation development, in 1969, ISRO (Indian Space Research Organization) was formed, which superseded the INCOSPAR. Since then, ISRO was on a mission to develop technologies for nation's space services and develop technologies independently (Exhibit-1 &

¹ HT, "ISRO Sets Space Record: Highlights of Successful Launch of Cartosat-2 and 103 Other Satellites", *Hindustan Times*, February 15, 2017.

² PTI, "PSLV can even launch 400 nano satellites: G Madhavan Nair", *The Economic Times*, February 15, 2017.

Exhibit-2). By 2017, ISRO became the sixth largest space agency in the world (Exhibit-3). In 2015, ISRO has an annual budget of \$1.2 billion³ (Exhibit-3).

As on 2015, global space industry was worth \$322.94 billion⁴. In that, commercial space business was worth 76% of the global space industry and 24% was of governmental space business (Exhibit-3).

ISRO maintains largest fleet of Remote Sensing (IRS) and Communication (INSAT) satellites. As on 2017, with the growing demand for earth observation, and fast communication, ISRO develops satellite based products, tools and applications for broadcasting, disaster management, weather forecasting, GIS (Geographic Information Systems), communications, telemedicine, and distance education.

ISRO developed reliable and cost efficient satellite launch vehicle such as Polar Satellite Launch Vehicle (PSLV). PSLV became favoured satellite launch vehicle for many foreign countries because of its cost efficiency and reliability. ISRO developed Geosynchronous Satellite Launch Vehicle (GSLV) for carrying heavier payload which carries geosynchronous communication satellites.

On February 15, 2017, ISRO set a world record by launching 104 satellites in a single PSLV-C37 mission. PSLV-C37 is the 39th flight and 38th consecutive successful PSLV mission for ISRO. Before launching PSLV-C37, on February 12, 2017, S.Somnath, Director, Liquid Propulsion Systems Center of ISRO, said “We are making a century by launching over 100 satellites at one go”⁵.

ISRO VISION

“Harness space technology for national development, while pursuing space science research and planetary exploration”⁶.

----- Indian Space Research Organization
On www.isro.gov.in (2016)

In 2008, ISRO could send 10 satellites in a single mission. On June 22, 2016, ISRO set a record launch of 20 satellites including one Cartosat-2 Series satellite and 19 co-passenger satellites in 36th flight of PSLV (PSLV-C34)⁷.

On December 18, 2014, ISRO experimented CARE (Crew Module Atmospheric Re-Entry Experiment) for manned space flight missions. The capsule reached an altitude of 80 km and landed safely in sea. ISRO has plans to develop a capsule which can hold three astronauts for one week in space. ISRO has plans to make manned space mission in 2021.

As on 2016, ISRO’s vision is to develop Reusable Launch Vehicle (RLV) with wings similar to NASA’s spacecraft (Exhibit-4). However these RLV required 5 km runways to land. The largest runway in India was of 2 km as on 2016. Hence, ISRO was planning to land RLV on sea water. A prototype of RLV was tested in May, 2016 by ISRO. It went on to 70 km

³ Tomar, A., “Top 10 Space Agencies in the World in 2017”, *TECHNIMOS*, 2017.

⁴ SF, “The Space Report - 2016”, *Space Foundation*, 2016.

⁵ Tiwari, S., “Here’s Everything You Need to Know About ISRO’s World Record Setting Launch of 104 Satellites in One Go Using PSLV-C37”, *India Times*, February 12, 2017.

⁶ ISRO, “Vision and Mission Statements”, www.isro.gov.in, 2016.

⁷ ISRO, “PSLV-C34/CARTOSAT-2 Series Satellite”, www.isro.gov.in, June 22, 2016.

altitude and landed in Bay of Bengal safely. ISRO would like to develop two more such prototypes before they actually develop the final RLV by 2030. ISRO also has plans to develop 5 km runway near Sriharikota, Andhra Pradesh for spacecraft landing purposes. According to ISRO Chairman, as on 2015, ISRO first would like to take stock of the projects on hand and finish of them before devising long term strategies and new projects. The projects going on in remote sensing satellites, launch vehicles, and communication satellites would be completed first. Later on, ISRO works towards the RLV, manned space missions, Venus, Moon, Mars, and Jupiter missions.

ISRO TRACK RECORD

“With each successful Launch our responsibility grows and we give emphasis to zero defect delivery”⁸.

----- Kiran Kumar, Chairman, ISRO
(*The Economic Times*, February 15, 2017)

ISRO transported their first communication satellite ‘Apple’ on bullock cart and a part of the rocket on bicycle (Exhibit-1). In early days of ISRO, scientists used to work like garage workers who make their hands dirty repairing leaking motor vehicles (A photograph of Dr.APJ Abdul Kalam with Dr.Vikram Sarabhai is presented in Exhibit-1). Over a period of time, technology has been improved, upgraded, evolved, customized reducing the costs to compare with global satellite launch rates.

On November 03, 2013, ISRO reached a major milestone of successfully launching Mars Orbiter Mission (MOM)-Mangalyan. With this India became, 1st Asian country and fourth in the world in a making Mars mission. Other countries which made Mars missions earlier were USA, Russia and European Union. The 2013 MOM-Maglayan made ISRO the first organization in the world which made a successful mars mission in its maiden attempt.

In 2016, ISRO could send 34 satellites into orbit; in which 33 were using Indian rockets and 1 satellite (GSAT-18) was sent with French company Arianespace⁹. Till February, 2017, ISRO has made 87 spacecraft missions (including 2 nano satellites), 60 launch missions, 8 student satellites, and 2 re-entry missions¹⁰. As on 2017, ISRO maintains largest fleet of communication satellites (INSAT) and remote sensing satellites (IRS). Till February 2017, ISRO launched 74 foreign satellites belonging to 20 different countries.

As on February, 2017, ISRO has completed its mission of providing India’s independent navigation system, with launch of seven Indian regional navigation satellites (IRNAA). This accomplishment reduced the India’s dependency on US Global Positioning System (GPS).

On May 05th, 2017, ISRO launched South Asian Satellite with GSLV Mk-II rocket; this satellite helps in South Asian regional cooperation. This satellite helped in TV broadcasting, tele-education, tele-medicine, and disaster management support. This satellite helps the neighbouring countries such as Maldives, Sri Lanka, Nepal, Bangladesh, and Bhutan.

SPACE COMPETITION

⁸ PTI, “ISRO Planning Launch of SAARC Satellite in March”, *The Economic Times*, February 15, 2017.

⁹ Arianespace SA is an MNC founded in 1980; produces, operates, markets and launches satellites; has portfolio of fleet; Till May 2017, it could launch 550 satellites; revenues: EUR \$1.433 billion (2015).

¹⁰ ISRO, “About ISRO”, www.isro.gov.in, February 2017.

“The US based SpaceX and French Arianespace simply cannot compete with the prices that are offered by ISRO”¹¹.

----- *The First Post* (February 13, 2017)

The earlier records of launching maximum number of satellites in single rocket launch are from Russia's launch of 37 satellites on June 19, 2014 and US's launch of 29 satellites in 2013 and ISRO's 20 satellite launch on June 22, 2016 (Exhibit-5). ISRO has made 20 satellites launch in PSLV-C34 mission, which included Cartosat-2 series satellite, Google made Skysat Gen2-1 satellite and 18 other satellites¹².

As on 2017, ISRO's low cost advantage may not last longer because of the latest technological developments happening in USA. India's low cost advantage depends on how fast ISRO can develop reusable launch vehicles and technologies. As on 2017, ISRO's reusable launch vehicle project called 'Avatar' would take another 9 years to complete. By that time, SpaceX may launch the technology globally into the market.

As on 2017, India is working towards a Unified Launch Vehicle (ULV) which will replace PSLV and GSLV. Unified Launch Vehicle has capacity to launch 15,000 kg on Lower Earth Orbit (LEO). While India is working towards ULV, US based SpaceX (of Elon Musk) is on next generation launch vehicle Falcon Heavy and Blue Origin¹³ (of Jeff Bezos) is working on New Glenn Rocket. These two launch vehicles will have capacity to launch 50,000 kg in to orbit¹⁴. SpaceX is also working on launch vehicle which can launch even 500,000 kg in interplanetary mission. NASA is working on Space Launch System (SLS) which can put 100,000 kg into space in a single mission.

ISRO's launch vehicle PSLV has flawless record of two decades. Antrix Corporation provides space services to foreign customers cheaper than its competition through ISRO. To restrict the competition from ISRO in space services, there was also lobbying happened in US to restrict foreign players for satellite launch services. As on 2017, nano satellite launch market was growing. Multi-launch of nano satellites might be a way to get into US markets for Indian players.

PSLV-37 PROJECT

“The ‘work horse’ rocket of the Indian space agency has a flawless record spanning over two decades, and has seen a spike in spaceflights in the XL configuration lately”¹⁵.

----- *The First Post* (February 13, 2017)

On February 06, 2017, ISRO told to IANS in Bangalore “we have tentatively decided to launch the satellites at one go around 9am into the sun-synchronous orbit around 500km above the earth”¹⁶.

¹¹ Tech2, “PSLV-C37 Launch: How Antrix Compares to Other Satellite Launch Services”, *The First Post*, February 13, 2017.

¹² FE Online, “President Pranab Mukherjee Congratulates ISRO for Satellite Launch”, *The Financial Express*, June 11, 2016.

¹³ Blue Origin is Washington based aerospace manufacturer; founded in 2000 by Amazon founder Jeff Bezos;

¹⁴ Tech2, “ISRO PSLV-C37 Launch: How Antrix Compares to Other Satellite Launch Services”, *The First Post*, February 13, 2017.

¹⁵ FP, “ISRO PSLV-C37 Launch: How Antrix Compares to Other Satellites Launch Services”, *The First Post*, February 13, 2017.

¹⁶ IANS, “ISRO to Launch Record 104 Satellites on a Single Launch Next Week”, *NDTV*, February 06, 2017.

PSLV-C37 launch vehicle carries 104 satellites consists of India's Cartosat-2 series satellite (known as Cartosat-2D), 2 nano satellites of ISRO (INS-1A and INS-1B), 96 USA's nano satellites, 1 nano satellite each from Israel, Kazakhstan, The Netherlands, Switzerland, and United Arab Emirates (UAE)¹⁷ (Exhibit-6). These nano satellites weighing 1.1 kg to 5 kgs are called 'Doves' or 'Flock 3p'. Among 96 US satellites, 88 belonged to a US based private space/earth imaging company known as Planet¹⁸. Dove constellation was used to image the earth at low cost.

PSLV-C37 dimensions include 320 tonnes weight, 44.4 meters long, carried 1,378 kg payload consisting of Cartosat-2D and 103 nano satellites. As on February, 2017, as far as Cartosat series satellites are concerned, only Cartosat-2E is left for ISRO to launch. Remaining all 6 Cartosat series satellites have been launched with PSLV-C37 mission (carried 6th satellite of series). The primary objective of INS-1A and INS-1B satellites is to demonstrate ISRO's payload technology, and provide a standard bus for launch on demand services.

On February 15, 2017, B.Jayakumar, Project Director, PSLV-C37 said "it was a complex mission", "but our team came up with very good solutions. The integration parts are also done very well by our team.So far ISRO has launched 226 satellites, out of which 179 are from foreign nations"¹⁹.

As on February 2017, ISRO fleet of rocket launchers consisted of three workhorses such as PSLV (Polar Satellite Launch Vehicle), GSLV (Geosynchronous Satellite Launch Vehicle), and GSLV Mk-III (Exhibit-7). These carriers are of 12 storied building height. The payload they can carry varies. PSLV can carry 2 times an Ambassador car weight payload, GSLV can carry 4 times an ambassador weight and GSLV Mk-III can carry 8 times an Ambassador car weight payload²⁰. Vikram Sarabhai Space center at Tiruvananthapuram was responsible for design and development of launch vehicles. PSLV was developed to launch to low earth orbit and Sun synchronous orbits. It made lunar and interplanetary missions successfully. GSLV was developed to launch heavier INSAT class of geosynchronous satellites into orbit.

PSLV is the same vehicle ISRO used in its 2008 moon mission Chandrayaan-1 and in 2013 Mars Orbiter Mission (MOM) Mangalyan. PSLV-C37 carried a payload of 1378 kg comprising Cartosat-2 series weighed 714 kg and remaining 103 satellites weighed 664 kg (Exhibit-8 and Exhibit-9).

PROJECT TIMELINE MANAGEMENT

"After a flight of 16 minutes and 48 seconds, the satellites achieved a polar Sun synchronous orbit of 506 kmIn the next 12 minutes, all 104 satellites successfully separated from the PSLV fourth stage in a predetermined sequence, beginning with Cartosat-2 Series, INS-1 and INS-2"²¹.

----- Indian Space Research Organization, Official Communiqué
The Hindu (February 16, 2017)

¹⁷ Jose, B., "ISRO to Launch Record 103 Satellites in one go next month", *India Today*, January 04, 2017.

¹⁸ Planet Labs, founded in 2010, a CA based earth imaging company; a privately help company; develops nano satellites called Doves.

¹⁹ Jagannath, G., "104 Satellites Put ISRO In Unique Orbit", *DNA India*, February 16, 2017

²⁰ ISRO, "Launchers – Overview", *Indian Space Research Organization, Department of Space, Govt. of India*, February 20, 2017.

²¹ TH, "ISRO Launches 104 Satellites in One Go, Creates History", *The Hindu*, February 16, 2017.

Online February 14, 2017, at 5:28AM, Mission Readiness Review Committee and Launch Authorization Board gave a go ahead signal for the PSLV-C37 launch²². The countdown started. The shortest countdown of 28 hours for the PSLV-C37 launch was started on early hours of February 14, 2017. Regarding countdown, P.Kunhikrishnan, Director, Satish Dhawan Space Center, said “nothing that the countdown time of 28 hours was the shortest of all PSLV missions so far”²³. ISRO was able to reduce the normal countdown of 52 hours to 28 hours in case of PSLV-C37 launch.

On February 15th, 2017, at 9:28 AM ISRO launched PSLV-C37 rocket with 104 satellites on board from Sriharikota spaceport in Andhra Pradesh. At 9:29 AM PSLV-C37 lift off normal as expected (Exhibit-10). It cruised at a speed of 27,000 km per hour (40 times the speed of an average passenger airline). At 9:36 AM fourth stage of the mission commenced. Both engines performed as expected. By 9:40 AM C-37 rocket has attained an altitude of 500 km. At 9:45 AM, Cartosat-2 satellite was ejected; followed by two ISRO’s nano satellites. At 9:45 AM PSLV-C37 rocket could place Cartosat-2 satellite in its orbit along with four other satellites. At 10:00 AM, ISRO confirmed the separation of all 104 satellites on board into orbit successfully. In a total period of 30 minutes from take-off, all the satellites were ejected into the orbit at their appropriate places in the orbit without any collision.

After the Cartosat-2D launch, at 10:25AM, ISRO’s Telemetry, Tracking and Command Network (ISTRAC) took over the control of the satellite. According to ISRO, as on February 15, 2017, ISRO would bring the satellite into operational configuration following which it provides the remote sensing services with panchromatic and multi-color cameras. According to ISRO Chairman, already 77 of the satellites started communicating with earth stations after the launch.

The placement and angle of 104 satellites in space container was such that no satellite will collide with another satellite while separation. The satellites have relative velocity of one meter per second while separating from launch vehicle. In 1,000 seconds satellite goes 1,000 meters away from vehicle. At an altitude of 500 kms, it would take vehicle 90 minutes to make a complete orbit. So within this time, the vehicle had to launch all 104 satellites from racks. Because of relative velocity, the distance between each satellite increases after separation from vehicle. According to ISRO, “The satellites will be ejected into orbit at different locations at different angles, at different times and different orientations”²⁴. Even one degree difference in angle combined with relative velocity ensures no two satellites collide. This theory worked successfully for ISRO. The arrangement of satellites in racks without colliding after separation from vehicle required engineering innovation at ISRO.

ISRO’s MOM Mangalyan was planned 6 months, and was 780 million kms flight to Mars. NASA’s Mars mission MAVEN was planned for 12 months, and was 712 million kms flight to Mars.

PROJECT COST ADVANTAGES

²² NNB, “ISRO Creates History by Launching More than 100 Satellites at once; PM Modi says ‘proud movement’”, *News Nation Bureau*, February 15, 2017.

²³ Jagannath, G., “104 Satellites Put ISRO In Unique Orbit”, *DNA India*, February 16, 2017

²⁴ Prasad, R. “How ISRO Plans to Launch 103 satellites on a single rocket”, *The Hindu*, January 21, 2017.

“Roughly half of its cost is recovered by the foreign satellites we are launching”²⁵.

----- -Kiran Kumar, Chairman, ISRO
(*The First Post*, February 08, 2017)

Over a period of time ISRO built many prototypes and developed electric batteries at 1/10th of the cost of commercially available batteries²⁶. In 2013, ISRO’s Mars Orbiter Mission, Mangalyaan was a low cost mission to compare with other global Mars Missions. ISRO spent \$74 million on Mangalyan; whereas NASA spent \$671 million on its MAVEN project (Mars mission) (Exhibit-11). In 2014, Prime Minister Narendra Modi said that an ISRO’s satellite launch mission did cost less than that made of Hollywood firm “Gravity”, whose cost was \$100 million. Commercial satellite launch is a growing business for ISRO.

PSLV-C37 mission cost was \$15 million (Rs 100 crore). On February 15th, 2017 mission of ISRO, with launch of 101 foreign nano satellites; ISRO could recover half of the cost of total 104 satellite launch of PSLV-C37 mission cost. ISRO’s efforts clearly showed how products can be made in resource constrained environment in emerging economies. Whereas, US Space manufacturer SpaceX’s²⁷ launch of Falcon-9 costs around Rs 500 crore and European Space Agencies Ariane-5 rocket launch costs Rs 721 crore.

As on February 2017, ISRO was working towards reusable launch vehicles. It was because it costs \$20,000 per kg to send people or instruments into space. 50% of the cost goes into launch vehicle. After the rocket was launched, the launch vehicle falls into the sea and was lost cannot be reused forever. If launch vehicle can be reused, the cost of transporting per kg into space would come down to \$5,000 from \$20,000 (Exhibit-4).

In 2015, ISRO’s annual budget was \$1.2 billion, whereas NASA’s annual budget was \$19.3 billion (Exhibit-3)²⁸. As on February 07, 2017, ISRO has earned \$100 million (Rs 600 crore) in revenues from foreign satellite launches through Antrix Corporation²⁹.

ISRO Jugaad

“We are not looking at it as a record of anything like that; we are just trying to maximize our capability with each launch, in trying to utilize that launch for the ability it has got and getting the maximum return”³⁰.

----- AS Kiran Kumar, ISRO Chairman
India Today (February 15, 2017)

Jugaad is getting things done in a resource constrained, uncertain environment bringing in flexibility and improvisation. In other words, that is getting things done when conventional wisdom fails. ISRO’s Mangalyan was the most laudable and successful example of Jugaad. They worked round the clock, with indigenous improvements and few resources in tight deadlines. ISRO built the final model of the Mars Orbiter from the start without making many iterations, as NASA does. They executed fewer ground tests, used components, modules and

²⁵ FP, “ISRO To Recover half of the cost of the record breaking PSLV-C37 launch from Foreign Customers”, *The First Post*, February 08, 2017.

²⁶ Swaminathan, R., “The PSLV C37 is not Just a Rocket, It is a Manifestation of a Worldview Unique to ISRO and Indian Scientists”, *First Post*, February 16, 2017.

²⁷ SpaceX is California based space manufacturing and space transport services firm; founded in 2002 by Elon Musk; has 6,000 employees as on 2017.

²⁸ <http://techimos.com/top-10-space-agencies-in-the-world-2017/>

²⁹ PTI, “Satellite Launch: ISRO to earn half the cost from fgn Parties”, *PTI Newd*, February 07, 2017.

³⁰ Jandial, S., “ISRO Creates History as PSLV Launches 104 Satellites in one Go”, *India Today*, February 15, 2017.

basic building blocks from their earlier missions. Lot of reuse with improvements happened in ISRO's Mars Orbiter Mission and also in PSLV-C37. ISRO was making frugal innovations in the process and product development. With Jugaad, ISRO overcame the opinion of Public Sector Company, and with minimal resources made itself as a world class institution in space exploration.

PSLV C-37 PROJECT CHALLENGES

“One worry is that these (103 satellites) are tiny satellites which at the best can have a life of one or two years; after that it really becomes space debris. Since they are small in size, they may not be amenable for tracking and finding out their positions and things like that. They become passive. To that extent, that worry is there”³¹.

----- G. Madhavan Nair, Former ISRO Chairman
(*The Economic Times*, February 15, 2017)

On February 15, 2017, PSLV-C37 Mission director B.Jayakumar said “it was a challenge to find real estate (on the PSLV rocket) to accommodate all the satellites.unique separation sequence was designed due to large number of satellites”³². As on February 2017, ISRO was facing challenges related to retaining human resources from foreign space applications companies who were paying fancy salaries. It was similar to how engineers from C-DAC and C-DOT were poached by MNCs and foreign players during telecom sector revolution in India. On February 15, 2017, at 10:03am, regarding PSLV-C37 mission, AS Kiran Kumar, Chairman, ISRO said “This was a very enjoyable mission. I congratulate the team. We faced many challenges before we accomplished this mission”³³.

APPLICATIONS OF CARTOSAT-2

“The main purpose of Cartosat-2 Satellite is the generation of imagery for cartography, environmental monitoring, disaster relief and event monitoring”³⁴.

--- *spaceflight101.com* (November 22, 2017)

The Cartosat-2 was supposed to provide remote sensing services, supporting coastal land usage regulations, distribution of water, creation of land usage maps and road network monitoring, etc. Cartosat-2 Series satellite has a life of 5 years. INS-1A and INS-1B have life time of one or two years.

GOING FURTHER

“This remarkable feat by @isro is yet another proud movement for our space scientific community and the nation; India salutes our scientists”³⁵.

----- Prime Minister Narendra Modi,
on *Twitter* (February 15, 2017)

As on 2017, ISRO is working towards single and two stage orbit vehicles, reusable launch vehicles, heavy lift launchers, human space flight projects, semi-cryogenic engines, and use

³¹ PTI, “PSLV can even launch 400 nano satellites: G Madhavan Nair”, *The Economic Times*, February 15, 2017.

³² Choudhury, S., “India Breaks Record for Launching Most Satellites from Single Rocket”, *The Wall Street Journal*, February 15, 2017.

³³ HT, “ISRO Sets Space Record: Highlights of Successful Launch of Cartosat-2 and 103 Other Satellites”, *Hindustan Times*, February 15, 2017.

³⁴ <http://spaceflight101.com/pslv-c37/cartosat-2d/>

³⁵ HT, “ISRO Sets Space Record: Highlights of Successful Launch of Cartosat-2 and 103 Other Satellites”, *Hindustan Times*, February 15, 2017.

of composite material for space applications. ISRO is working toward GSLV Mark III using C25 cryogenic engine. As on February 2017, ISRO would like to partner with private sector in developing satellites; so that ISRO can concentrate on their core competency and research and deep space exploration³⁶.

As on 2017, ISRO was working towards Chandrayaan-2 with orbiter, lander and rover to send to Moon. They have also announced plans of future missions for Mars, Jupiter and Venus. ISRO's Mars Orbiter Mission-II would probably place a robot on Mars surface and was planned for 2021-22. Its maiden Venus mission probably includes the Venus orbiter.

As on February 2017, Chandrayaan-2 experiments were going on at their facilities in Mahendragiri in Tamil Nadu and Challakere in Karnataka. On February 07, 2017, Kiran Kumar, Chairman, ISRO said "It is an indigenous development and tests are on. It's a control descend. So it has engines that allow a control descend". Chandrayaan-2 mission plans to land on moon. The lander lands on moon and deploy the rover. The orbiter, lander, and rover will perform mineralogical and elemental studies of lunar surface. The mission is planned to launch during 1st quarter of 2018. As on 2017, manned missions were not ISRO's priority; improving space infrastructure was their priority, according to ISRO Chairman.

For 2018, ISRO has plans to launch 8th satellite of Cartosat series, Cartosat-3 satellite. It is advanced version of Cartosat-2 with improved spatial and spectral characteristics. In another two years, ISRO will celebrate its golden jubilee (2019) with amazing plans and portfolio of projects on its front.

On PSLV-C37 success, ***"This day shall go down as a landmark in the history of our space program.....I urge ISRO to continue to strive for the progress of our space capabilities"***³⁷.

----- Honourable Pranab Mukherjee, President of India
DNA India (February 16, 2017)

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³⁶ Khandelwal, S. "With 104 Satellites, ISRO PSLV C-37 Mission Will Create History", *The Quint*, February 14, 2017.

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40. <https://thewire.in/108680/satellites-isro-cartosat-doves/>

Exhibit 1: ISRO Uniqueness



Dr Vikram Sarabhai and Dr. Abdul Kalam; From early stages of Indian Space journey



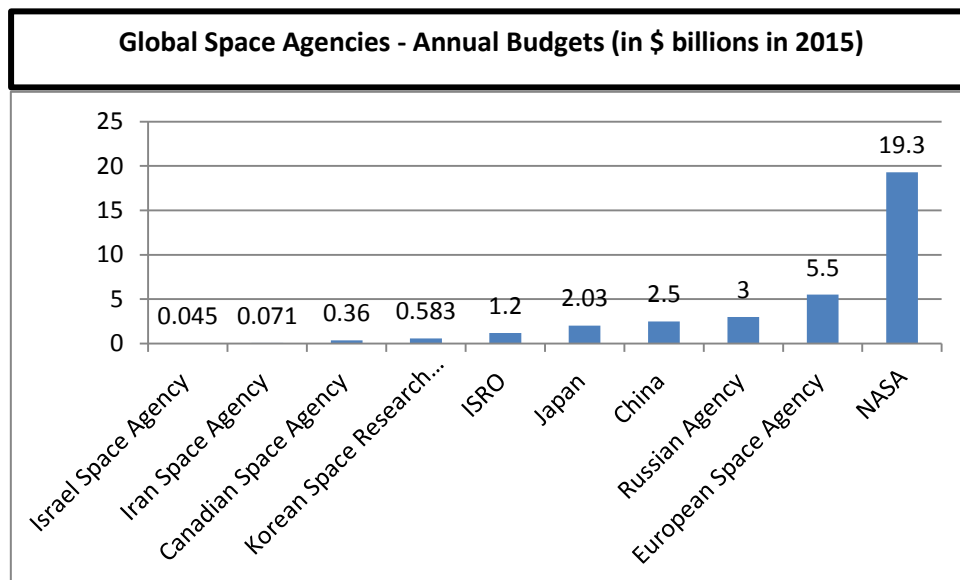
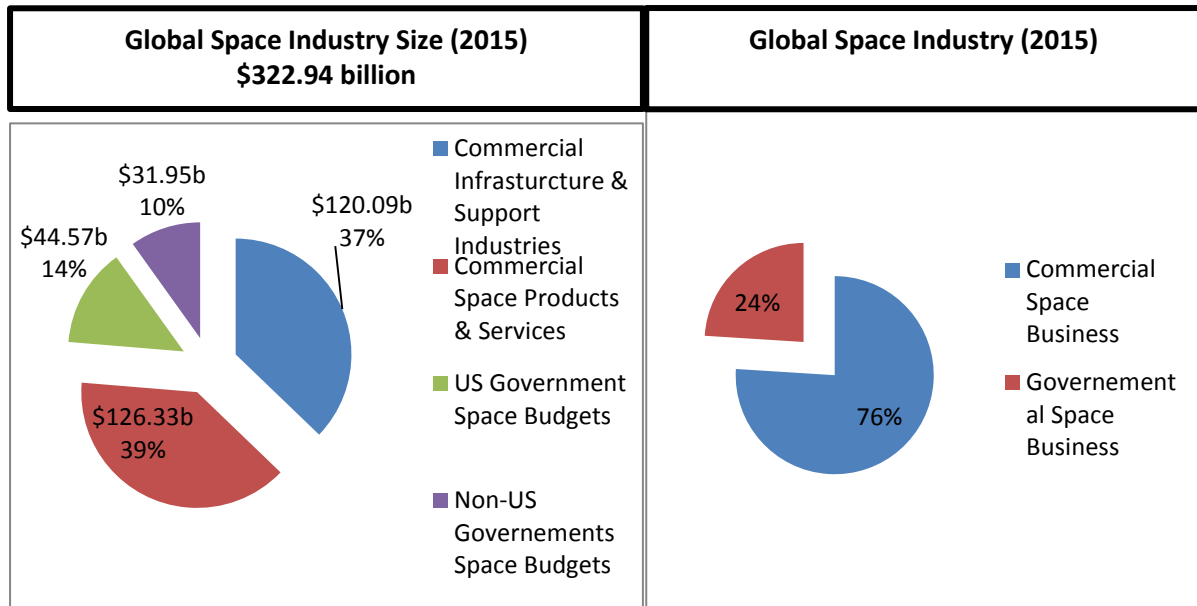
(Source: 1. <http://tech.firstpost.com/news-analysis/the-pslv-c37-is-not-just-a-rocket-but-is-a-manifestation-of-a-worldview-unique-to-isro-and-indian-scientists-362556.html>
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Exhibit 2: ISRO Major Milestones

Year	Major Milestone in ISRO History
2017	On February 15, 2017, Launched 104 satellites in one go (PSLV-C37 mission)
2016	ISRO successfully tested Reusable Launch Vehicle (RLV)
2016	Launched 20 satellites in a single mission
2016	Cartosat series satellites launch started for Indian regional navigation system purposes.
2014	ISRO made successful Mangalyan (Mars Orbiter) mission with \$75 million;
2008	ISRO's first moon mission-Chandrayaan-I; sent an orbiter to moon;
1993	PSLV (Polar Satellite Launch Vehicle) was developed; it made missions such as Chandrayaan and Mangalyan.
1984	Indo-Soviet manned space mission
1982	First INSAT (Indian National Satellite System) series of satellite was launched; useful for radio broadcasting, telecommunications and metrological services.
1981	APPLE, geo-stationary communication satellite launch was successful;
1980	Rohini Satellite (SLV-3) was successfully placed in orbit.
1979	SLV-3, First experiment of satellite launch; satellite could not be placed in orbit;
1979	Bhaskara-I, an experimental satellite for earth observation was launched
1975	Aryabhata India's First Satellite was launched from a Russian Facility
1972	Space Commission and Department of Space Setup
1969	On August 15, 1969, ISRO formed under Department of Atomic Energy
1967	Satellite Telecommunication Earth Center was set up at Ahmedabad
1963	First Sound Rocket Launch from Thumba Equatorial Rocket Launching Station
1962	INCOSPAR (Indian National Committee for Space Research) formed by Department of Atomic Energy on February 16, 1962

(Source: <https://www.isro.gov.in/about-isro/isros-timeline-1960s-to-today>)

Exhibit 3: Global Space Industry

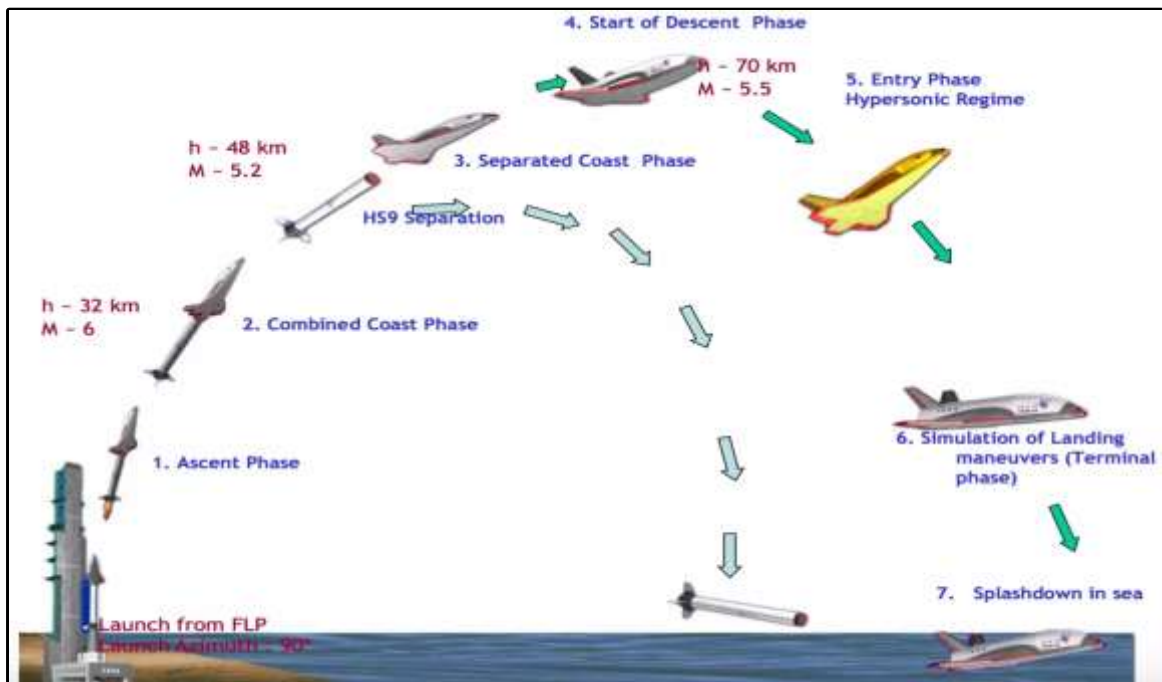


(Source: 1. https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OV_ERVIEW.pdf)

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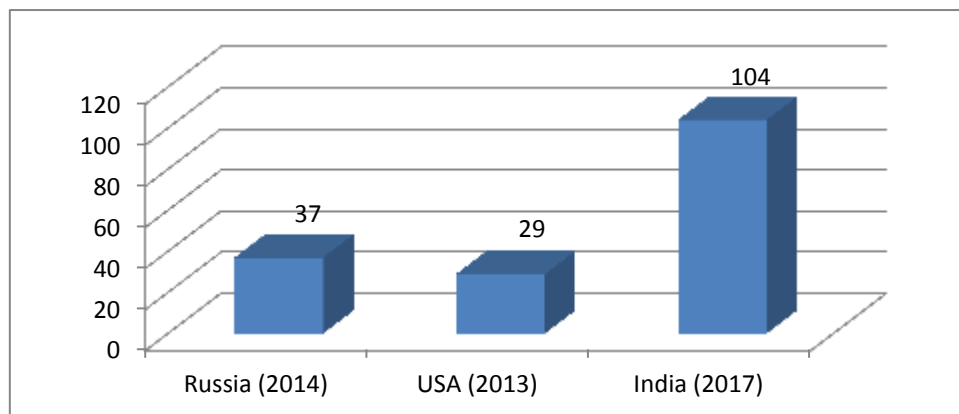
3. <http://techimos.com/top-10-space-agencies-in-the-world-2017/>)

Exhibit 4: Reusable Launch Vehicle (RLV)



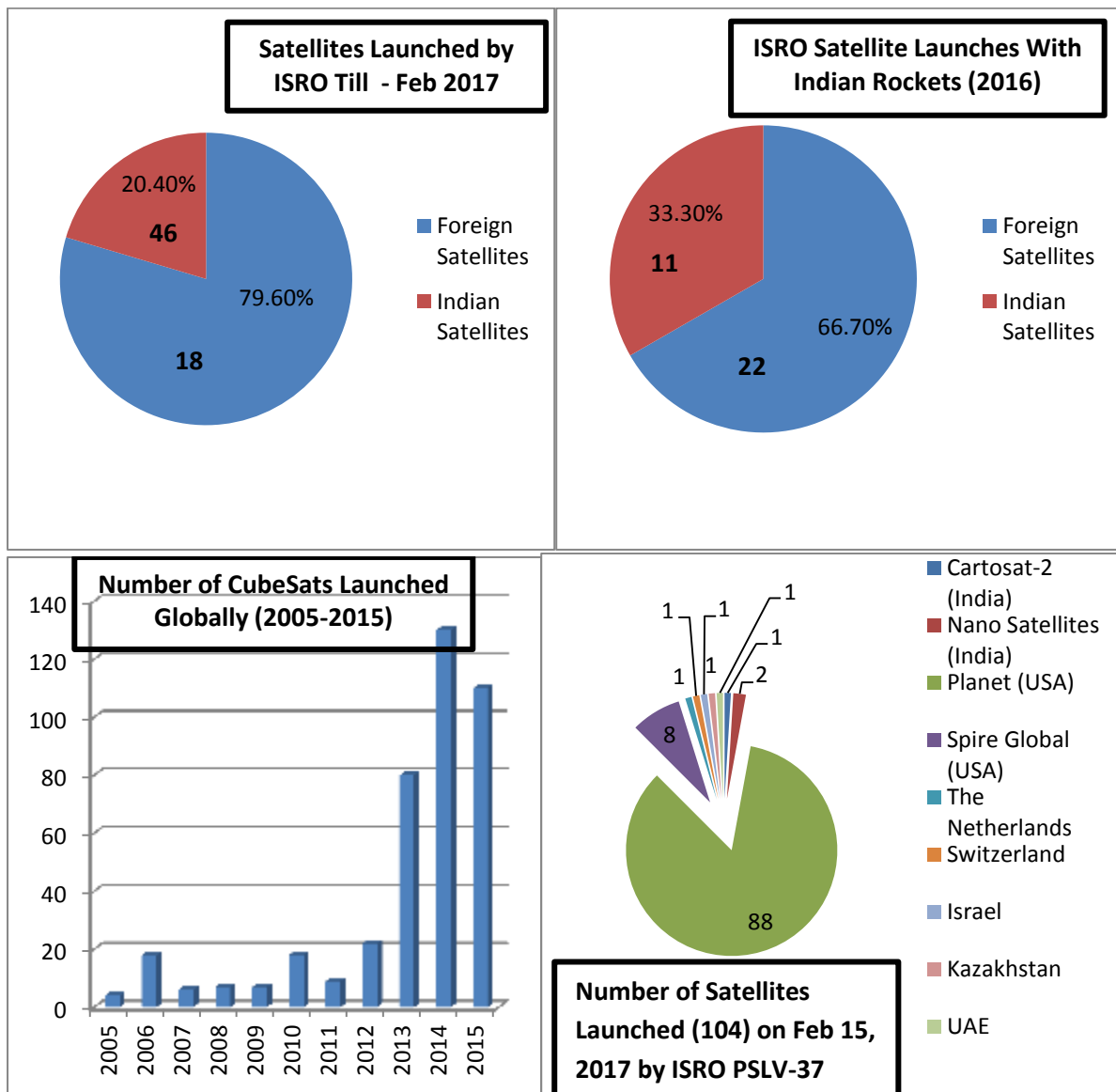
(Source: <https://thewire.in/38312/isros-reusable-launch-vehicle-what-happened-and-what-next/>)

Exhibit 5: Record Number of Satellites in 1 go



(Source: <http://blogs.wsj.com/indiarealtime/2017/02/15/india-breaks-record-for-launching-most-satellites-from-single-rocket/>)

Exhibit 6: Satellites Launched by ISRO



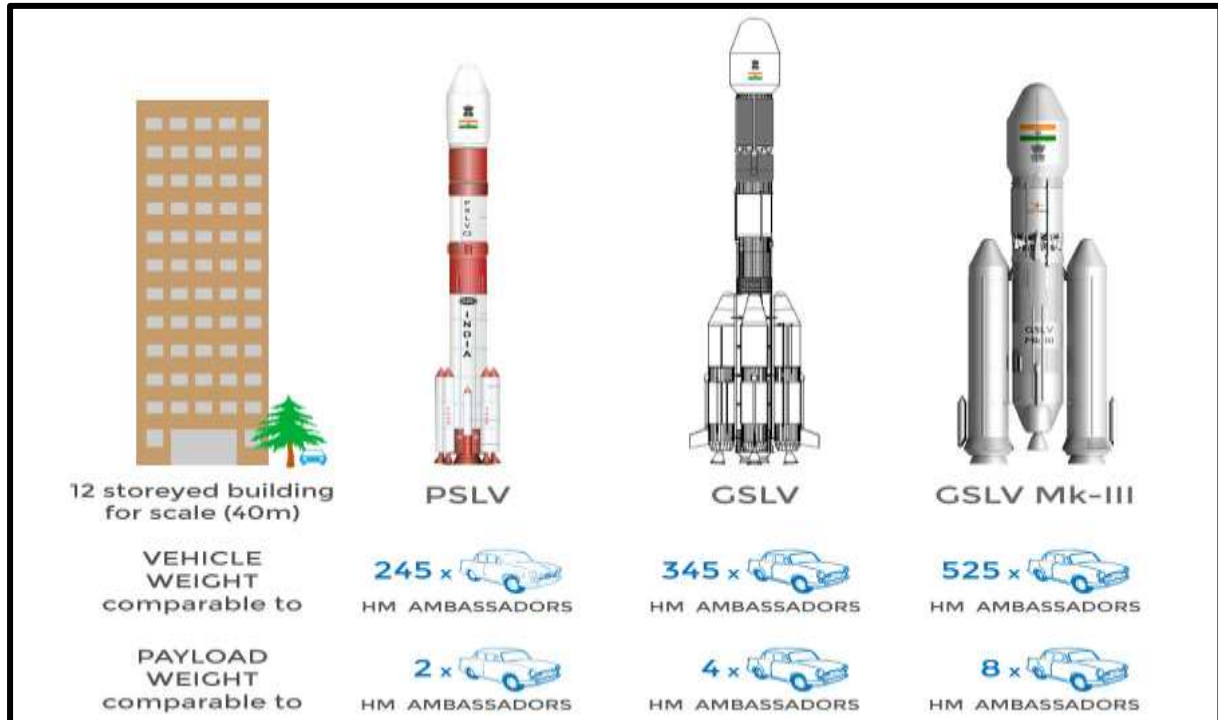
(Source: 1. <http://www.isro.gov.in/missions-0>

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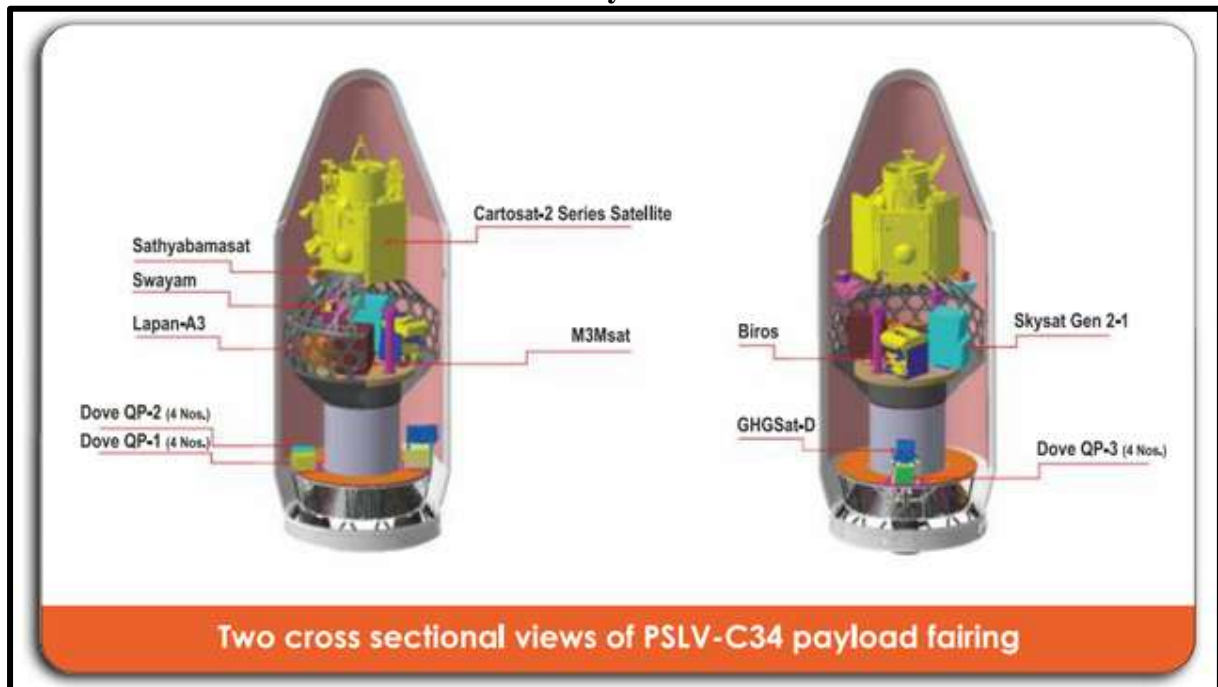
4. <http://indianexpress.com/article/india/isro-satellite-rocket-launch-live-updates-video-cartosat-planet-4525639/>)

Exhibit 7: ISRO Satellite Launch Vehicles



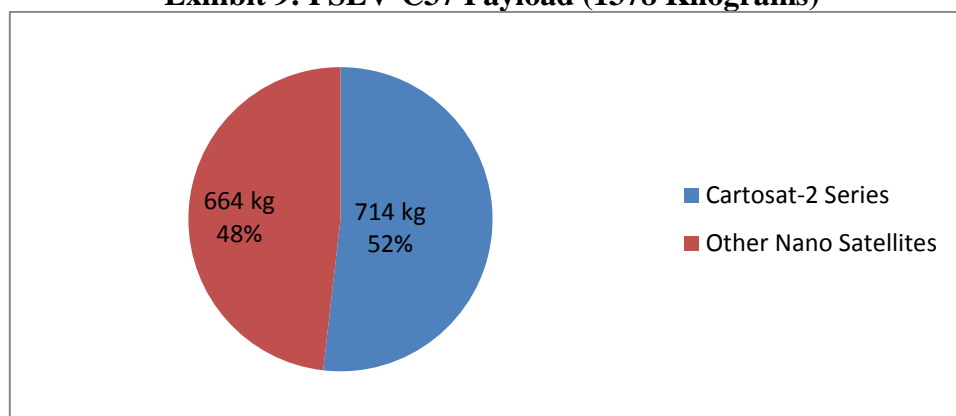
(Source: <http://www.isro.gov.in/launchers>)

Exhibit 8: PSLV - Payload/Satellite Racks



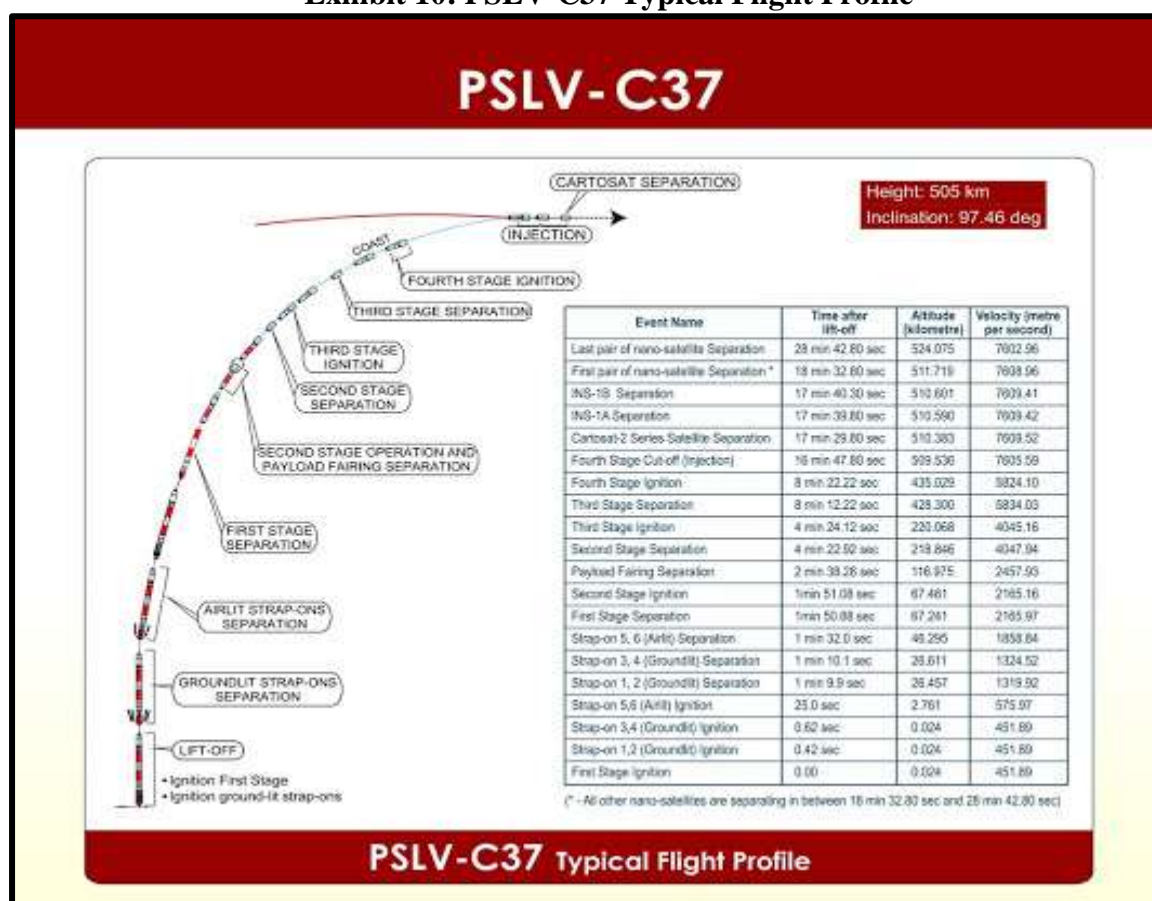
(Source: <http://tech.firstpost.com/news-analysis/the-pslv-c37-is-not-just-a-rocket-but-is-a-manifestation-of-a-worldview-unique-to-isro-and-indian-scientists-362556.html>)

Exhibit 9: PSLV-C37 Payload (1378 Kilograms)



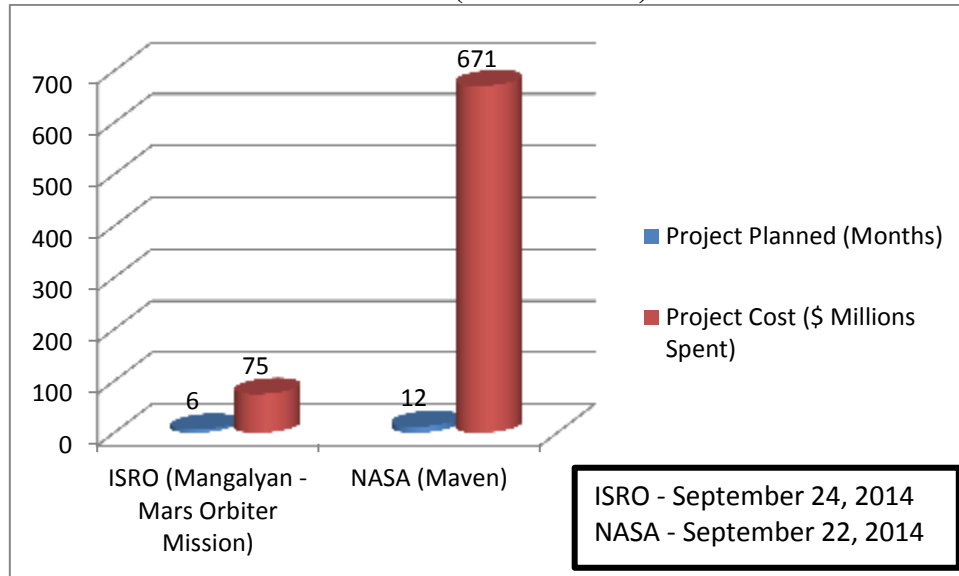
(Source: <http://www.hindustantimes.com/india-news/final-countdown-isro-hours-away-from-record-launch-of-104-satellites-into-space/story-yfC70LKVupmiagXWvnW0I.html>)

Exhibit 10: PSLV-C37 Typical Flight Profile



(Source: <http://tech.firstpost.com/news-analysis/isros-record-breaking-pslv-c37-mission-here-is-how-to-follow-the-launch-as-it-happens-362197.html>)

Exhibit 11: Mars Missions (Time & Cost) – ISRO vs. NASA



(Source: <http://m.dailyhunt.in/news/india/english/the+better+india-epaper-thebett/from+the+first+rocket+to+the+launch+of+104+satellites+isro+has+always+been+the+king+of+jugaad-newsid-63906611>)

TEACHING NOTES

Title of the Case: ISRO: 104 Satellites in 1 go

Synopsis of the Case: On February 15, 2017, ISRO set a world record by launching 104 satellites in single PSLV-C37 mission. This mission has several records such as number of satellites, record count down time of 28 hours, cost management, time management, and Jugaad. They executed the project with minimal resources and component reuse. Half of the project cost was acquired by accommodating 101 nano foreign satellites in the mission with commercial view. ISRO was heading with many plans with low cost missions to compare with international space agencies. This case describes the ISRO's PSLV-C37 project management by managing time, cost and risks.

Target Audience: Post Graduate/MBA

Applicable Courses: Project Management/
General Management

Difficulty Level: Moderate

Specific Pre-Requisites: The student should have an understanding of a business organization. Going through any course/book of *Principles of Management* before reading this case would be helpful to the student; however it is not mandatory.

Learning Objectives: The learning objectives of the case study include:

- ❖ To highlight the project management knowledge areas to learners
- ❖ To describe project characteristics in technology projects
- ❖ To illustrate project time management with limited resources
- ❖ To highlight project execution with low costs to compare with international mission costs.
- ❖ To describe project risks in high technology projects

The above specified learning objectives are very important playing the key role in *Project Management* course.

Research Methodology: The reference articles were collected from newspapers and magazines such as *The Economic Times*, *Business Standard*, *Financial Express*, *Business Line*, *The Economist*, *India Today* and *The Times of India*, etc. The corporate website of ISRO was browsed for launch vehicles details and for their vision. The collected data is gathered, analysed and necessary graphs and diagrams were drawn. The major points gathered from content analysis based on secondary research and were classified as ISRO Vision, ISRO Track Record, PSLV-C37 Project, Project Time Management, Project Cost Management, ISRO Jugaad, Challenges and Going Further. The keywords used in search were "ISRO PSLV-C37", "104 Satellites", "ISRO world record", "uniqueness of PSLV-C37", "ISRO Jugaad", etc.

TEACHING PLAN AND ANALYSIS:

Suggested Teaching Plan: This case study can be discussed after explaining the concepts such as project characteristics, project planning, project time management, project cost

management, and project risk management in *Project Management* course. For a 90 minute class, detailed teaching plan is as given in Table 1:

Table 1: Detailed Teaching Plan for the Case Study

SL.No	Topic to Discuss	Duration (In Minutes)
1.	Case Reading and Understanding	30 Minutes
2.	Teach “Project Characteristics” and Discuss Question# 1	10 Minutes
3.	Teach “Project Time Management” and Discuss Question# 2	10 Minutes
4.	Teach “Project Cost Management” and Discuss Question# 3	10 Minutes
5.	Teach “Project Risk Management” and Discuss Question# 4	10 Minutes
6.	Teach “Meaning of Jugaad” and Discuss Question# 5	10 Minutes
7.	Concluding Remarks and Windup	10 Minutes

Case Study Discussion Questions:

1. Is ISRO’s PSLV-C37, a project? Justify your argument.
2. How do you say that PSLV-C37 project managed time efficiently? Discuss.
3. To compare with NASA’s missions, ISRO projects’ costs were less. Compare ISRO PSLV-C37 mission cost with other similar launches of the world.
4. What were the challenges faced by ISRO in launching of 104 satellites in a single mission? Discuss.
5. Did ISRO succeed in its mission with minimal resources with a philosophy of “Jugaad”? Discuss.

CASE ANALYSIS

1. Is ISRO’s PSLV-C37, a project? Justify your argument.

Analysis: PSLV-C37 mission is a project; it has exhibited following characteristics:

- ❖ It is not a repetitive task; it is a unique task which results into positive outcome.
- ❖ It has certain time limits; it has mission begin date and end date.
- ❖ It was executed by the ISRO team
- ❖ It was managed with time, cost, scope and quality parameters
- ❖ The project progress can be tracked.

2. How do you say that PSLV-C37 project managed time efficiently? Discuss.

Analysis: The time management of PSLV-C37 project was done as follows:

- ❖ Project was planned a head of time.
- ❖ They have established a record count down time with continuous progress tracking
- ❖ Technical Events were scheduled as per the project environmental constraints
- ❖ Task dependencies were handled with great care with perfection.
- ❖ Satellites ejection was planned without any collision with proper time estimations; entire operation was finished in just 30 minutes after launch.

3. To compare with NASA’s missions, ISRO projects’ costs were less. Compare ISRO PSLV-C37 mission cost with other similar launches of the world.

Analysis: The project cost management aspects in PSLV-C37 mission were as follows:

- ❖ ISRO spent Rs 100 crore on PSLV-C37 project.
- ❖ Half of the cost was acquired by launching 101 foreign nano-satellites with commercial angle in the same mission.
- ❖ Cost was reduced with component reuse, modularization, etc.
- ❖ US Space manufacturer SpaceX's launch of Falcon-9 costs around Rs 500 crore and European Space Agencies Ariane-5 rocket launch costs Rs 721 crore.
- ❖ ISRO was also working towards reusable launch vehicles.
- ❖ ISRO human resources skill level was high improving the accuracy of mission, so that costs are curtailed; it is evident from 38 successful launches of PSLV.

4. What were the challenges faced by ISRO in launching of 104 satellites in a single mission? Discuss.

Analysis: With PSLV-C37 mission, ISRO faced following challenges:

- ❖ With record short countdown time, time management became a challenge for the ground level staff.
- ❖ Finding real estate for the 104 satellites on board the launch vehicle was another challenge the team faced.
- ❖ Satellite separation sequence during launch was major challenge with time separation avoiding collision.
- ❖ Future space debris is a challenge with nano-satellites weighing 1 or 2 kg with one or two years of life time. After their life time, finding them and locating them in space is major challenge.
- ❖ ISRO's another challenge is poaching of their human resources by foreign multinational space companies with hefty salaries.

5. Did ISRO succeed in its mission with minimal resources with a philosophy of "Jugaad"? Discuss.

Analysis: The Philosophy of Jugaad is implemented in ISRO when conventional wisdom might fail:

- ❖ ISRO applied "Jugaad", executed project with minimal resources in an uncertain environment.
- ❖ They worked with indigenous resources, and in tight deadlines
- ❖ ISRO Built the prototypes (Ex: MOM) and models in first instance without making iterations as NASA does.
- ❖ ISRO did lot of reuse with improvements in PSLV-C37 mission.
- ❖ ISRO executed fewer ground tests, used components, modules and basic building blocks from their earlier missions.

Further Readings:

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4. Sudhakar, G.P. (2012), "A Model of Critical Success Factors for Software Projects", *Journal of Enterprise Information Management*, Emerald Group Publishing Limited, UK, Vol. 25, Issue 6, 2012, ISSN: 1741-0398, Pp. 537-558.

About the Author

Dr.Goparaju Purna Sudhakar, PhD, PMP with over a decade of IT industry experience and another decade of academic/research experience is currently working as Faculty Member at The ICFAI University Group in Hyderabad, India. He worked in **USA, UK, Ireland, Finland and India**. He has **M.Tech. Executive MBA, PMP**. He was awarded **PhD** in Business Administration from Aligarh Muslim University, India. He was consultant to companies such as IBM, Siemens, Interwoven, Wipro, Citicorp, Nokia, Salomon Smith Barney, SIAC, DSET Corporation, IONA Technologies and also visiting faculty. He authored or edited 16 books and published over 60 papers. He is on the editorial Board of a Romanian and a Brazilian Journal. He is author of *Software Development Teams: Performance, Productivity and Innovation* (Prentice-Hall, 2016), *Global Organizational Behavior* (LAP Lambert Academic Publishing, Germany, 2012), *Project Management FAQ* (Galgotia, 2012), *Elements of Software Project Management* (Prentice-Hall, 2010), *Project Management: Training Manual* (Akansha, 2010), and *Business Essentials for Software Professionals* (Excel Books, 2008).

He is member of All India Management Association (AIMA). He received Best Teacher (Management) award in 2015 from MTC Global. He won gold medal in Manager's Olympiad-2016 conducted by UNICOM at DevOps Conference in Bangalore. He received Outstanding Paper award at National Conference on Management Research - Contemporary Perspectives, ICBM - School of Excellence, Hyderabad on 24-Sep-2016. He is on Program Committee of several national and international conferences. The reuse domain software product he managed, Scorpis was identified as one among the top 100 IT innovations by NASSCOM (2007). He can be contacted at purna24@hotmail.com