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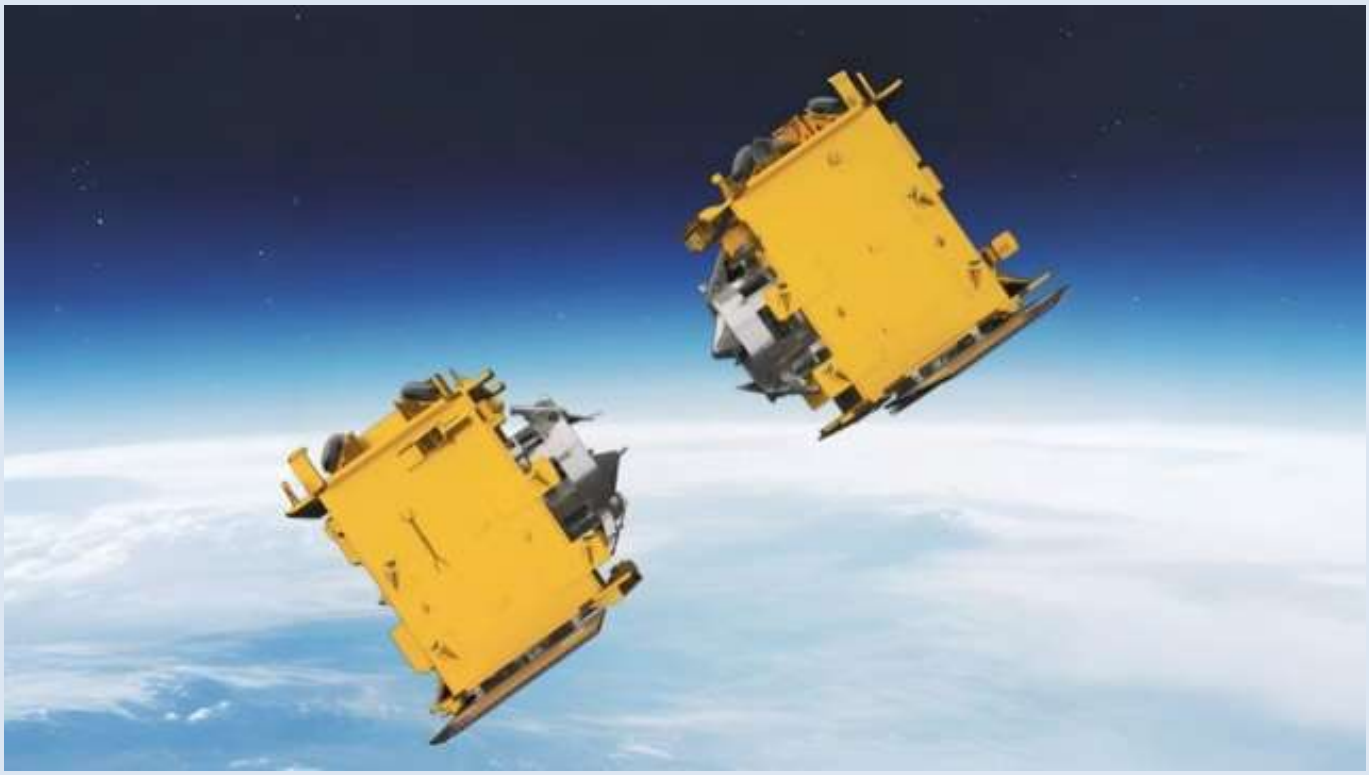
Anatomy of the Space Docking Experiment

TH Anand Rao
Senior Fellow, Centre for Air Power Studies



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The Indian Space Research Organisation (ISRO) successfully achieved a docking between two satellites on January 16, 2025, in its Space Docking Experiment (SpaDeX) mission. The mission was launched on the PSLV-C60 rocket on December 30, 2024.[1] The mission is a significant step forward in the development of space docking technology. The success of the docking experiment is a milestone towards bringing India closer to achieving its ambitious goals in space. The SpaDeX is a technology demonstrator mission to showcase in-space docking between small satellites. The mission's success has made India the fourth space-faring nation globally to develop docking capabilities. The US, Russia and China have already mastered this complex technology, which is crucial for all spacecraft operations in space, such as docking with a space station, return missions from the Moon, and Rendezvous and Proximity Operations (RPO).

The Mission

On December 30, 2024, the PSLV rocket deployed two identical satellites at an altitude of 470 km in a circular orbit. The satellites SDX01 (chaser) and SDX02 (target) were inserted into orbit with a slight time delay and a relative velocity to keep them apart and allow them to drift away from each other before the docking experiment. Each satellite weighs around 220 kilograms. The docking experiment commenced after testing and calibration of all onboard sensors. The algorithms were also tested on the ground before giving the command prompts for autonomous docking. The process involved a very delicate procedure of the chaser satellite approaching the target satellite in a controlled manner at a relative speed differential of 10 millimetres per second, aligning the docking ports and finally executing the handshake when all parameters were within limits. This process took place in incremental stages with the distance between the satellites being reduced from 20 kilometres to 15 metres, then 3 metres, stabilising before moving further closer.[2]

SpaDeX has demonstrated docking and undocking capabilities between satellites. This includes transferring power and operating scientific payloads. The SDX01 and SDX02 are controlled as a single satellite after the docking. Further, the mission completion indicates that the satellites are undocked and start functioning independently. [3]

The Objectives

The primary objective of the SpaDeX mission is to demonstrate technology for satellite rendezvous, docking and undocking between two small satellites in low earth orbit. The secondary objectives are to accomplish the transfer of electric power between the docked satellites, satellite control after docking, and payload operations after undocking.[4]

The Technology

The technologies required for such precise manoeuvring of satellites in close proximity involve multiple complexities like designing the hardware components, integrating them and running accurate software programmes and algorithms. The propulsion system and the thrust control mechanisms are equally complex. Moreover, the mission has to be monitored and controlled from Earth, which requires visibility in space through satellite surveillance and tracking infrastructure. The docking mission involves several new sensors, such as Laser Range Finder, Rendezvous Sensor, Proximity and Docking sensor and so on, that take precise measurements while the two satellites approach each other. On-board processors determine the relative position and velocity of the other satellite. Mastering these technologies will pave the way for completely autonomous systems for future missions that would involve docking or RPO.[5]

The docking system needs to be compatible with the systems in use by other countries, as this would enable participation in global space programmes. The International Docking System Standard (IDSS) is used by spacecraft going to the International Space Station. India must have a similar docking mechanism. India's docking system that is being tested is similar to the IDSS but uses two motors as compared to the 24 used in IDSS. In addition, India's docking test is conducted with two identical satellites. Further docking experiments with dissimilar satellites should also be done to consolidate the docking technology.[6]

Why the Mission is Important

Docking is the outcome of a successful RPO. Docking unfolds several possibilities in space like on-orbit servicing, on-orbit refuelling, on-orbit inspection and so on. These activities can facilitate satellite life extension and avoid the need to replace satellites when they reach their end of life. Further, docking capability is vital for India's lunar and Mars missions to bring spacecraft back. Docking technology also enables the assembly of space station modules and the transit of humans into a space station. Such a capability will provide the building blocks for the assembly of the Bharatiya Antriksh Station, which is to begin in 2028.[7]

Docking Capability is Not New

Docking experiments started back in the 1960s, along with the development of co-orbital satellites. The Americans were the first to achieve a docking in 1966, as part of the Gemini programme, when the Gemini VIII capsule docked with a target spacecraft. It was a crewed mission orbiting the Earth. Later, in 1967, the Soviet Union demonstrated an uncrewed automated docking of Kosmos 186 and Kosmos 188 satellites. China joined the elite group in 2011 when the unmanned Shenzhou 8 spacecraft docked with the Tiangong-1 space laboratory. A year later, China conducted the first crewed space docking, with

Shenzhou 9 docking with Tiangong-1. India has become the fourth country globally to have space docking technology on the completion of the SpaDeX mission.[8]

Delays and Challenges

The SpaDeX mission is challenging because of the requirement of very precise measurements and highly accurate execution. There were two attempts on January 07 and January 09 to bring the satellites closer, but they had to be aborted. The docking could not happen as the satellites were drifting more than anticipated.[9] More attempts were planned after stabilising the satellites and ruling out any system anomalies. Had the docking not been successful on January 16, 2025, in the planned window, it could have been delayed up to March 2025, when the next window would be available. This is not an abnormal situation, as multiple trials have to be undertaken before a final attempt. In an interview with the media, the Chairman of ISRO, Dr S. Somanath, emphasised that it was India's first attempt at docking, and every first attempt comes with challenges. He further clarified that the docking exercise would be undertaken only when all sensors are fully calibrated and tested to satisfaction.[10]

What Next

The docking procedures will eventually be perfected in due course. The experience gained in this experiment needs to be translated into more complex experiments, gradually progressing to the docking of human-rated spacecraft. India also needs to have the capability of on-orbit refuelling, servicing, and inspection of satellites. Docking technology is also an enabling capability for in-orbit assembly of India's space station. Furthermore, this docking technology would facilitate sample return missions from the Moon, like the Chandrayaan-4 mission. All this will only be possible with adequate space surveillance and tracking capabilities. India needs to create a robust space observation capability for situational awareness. This will require infrastructure like radars, optical telescopes, radio telescopes, geo-locating sensors, laser ranging sensors, space weather forecasting sensors, and even sensors in space.[11]

Conclusion

The SpaDeX is a groundbreaking achievement, placing India alongside select space-faring nations that possess the capability of docking in space. This will open up multiple possibilities for space exploration. It will also open the doors for future sample return missions and human missions to the Moon and other celestial bodies. The assembly of India's space station is also dependent on the mastery of docking procedures. The interoperability of docking ports and systems in future satellites and spacecraft with IDSS is necessary for participating in collaborative space exploration missions with other countries.

Notes:

[1] Press Information Bureau, "SpaDeX Mission: Revolutionising Space Exploration," https://pib.gov.in/PressReleasePage.aspx?PRID=2093369. Accessed on January 16, 2025.

[2] Pallava Bagla, "ISRO Trial For Historic Space Docking, Satellites Close In Till 3 Metres", *NDTV*, January 12, 2025, India News section, https://www.ndtv.com/india-news/isro-set-to-script-history-as-2-indian-satellites-close-in-for-handshake-7454077. Accessed on January 12, 2025.

[3] Ibid.

[4] Indian Space research Organisation, Department of Space, "SpaDeX Mission," https://www.isro.gov.in/mission_SpaDeX.html. Accessed on January 14, 2025.

[5] Express Web Desk, "ISRO SpaDeX Docking Mission Live Updates: In a trial attempt at docking, SpaDeX satellites successfully come 3 meters to each other, says ISRO", *The Indian Express*, January 12, 2025, Science section, https://indianexpress.com/article/technology/science/isro-spadex-docking-mission-live-updates-9773511/. Accessed on January 12, 2025.

[6] Anonna Dutt, "ISRO to attempt 'docking' satellites in space: What it means, why it matters for future missions," *The Indian Express*, January 14, 2025,Explained Sci-Tech section, https://indianexpress.com/article/explained/explained-sci-tech/isro-docking-satellites-attempt-9774607/. Accessed on January 14, 2025.

[7] Press Information Bureau, n.1.

[8] Bagla, n.2.

[9] Dutt, n.6.

[10] "ISRO SpaDeX Docking Mission: Satellites Come Within Three Metres In Trial Attempt", *DD News*, January 12, 2025, https://ddnews.gov.in/en/isro-spadex-docking-mission-satellites-come-within-three-metres-in-trial-attempt/. Accessed on January 14, 2025.

[11] Bagla, n.2.