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INDIA PROGRESSES DEVELOPMENT OF ADVANCED SPACE TECHNOLOGY

Gp Capt Vivek Kapur
Senior Fellow, CAPS

Introduction

India's space agency, Indian Space Research Organisation (ISRO), commenced working on developing a space launch capability in the late 1970s. Success with its satellite Launch Vehicle (SLV)-3 was first achieved in 1980[1]. SLV-3 was capable of placing a small 40 kg payload into low earth orbit (LEO)[2]. Hence SLV-3 was not a really usable space launch capability as most satellites of the time weighed above several hundred kilograms and orbits such as polar orbits and geosynchronous (GSO), geostationary transfer orbits (GTO), and Geosynchronous equatorial orbits (GEO) were entirely beyond SLV-3's capability. ISRO then put effort into developing more powerful launch vehicles such as the Polar Satellite Launch Vehicle (PSLV)[3] and Augmented Satellite Launch Vehicle (ASLV)[4]. Both ASLV and PSLV proved to be quite capable. However, success was achieved after a few failed launch attempts of these more powerful launch rockets. The first PSLV was launched in year 1993 and achieved success a year later[5]. In recent years, ISRO has worked on developing its Geosynchronous Satellite Launch Vehicle (GSLV) in increasingly more powerful variants from GSLV to GSLV-Mk-3. Conventional launch rockets are one use expendable vehicles. One use rocket carries its payload to a designated point in space at a predetermined velocity. Most space launch rockets are multistage vehicles. As each stage is used up (its fuel is fully burnt) it is jettisoned to avoid carrying non-productive dead weight any further than absolutely necessary. Thus, entire launch rocket is progressively discarded after its use. The jettisoned stages of the rocket burn up in the atmosphere; with surviving structures being destroyed on impact with the ground or falling into oceans, depending upon the location of the launch site. Each space launch has traditionally required a complete freshly built rocket to be used. This makes the cost of placing each kilogram of payload into space very high. Considerable thought has been devoted by all space faring nations to devise means of reducing launch costs.'

Reduction of Launch Costs

Even a cursory look at the means of reducing the cost of launching objects into space easily identifies the 'one time use' nature of the space launch rocket as a major contributor to the high cost of launching objects into space. Development of a launch vehicle that could be reused appeared to be the logical step towards reducing the cost of space launches. There are many possible ways of reusing launch vehicles.

The first such attempt at developing a reusable launch system was development of the Space Shuttle by the US. The Space Shuttle involved development of a large winged vehicle that could carry reasonable payload and crew to orbit and return via a glide to land like a conventional aircraft.[6] This vehicle was provided with its own integral rocket engines. The aim of the program was to make available cheap, regular and fast access to space[7]. For launch from Earth the US Space Shuttle used its three integral rocket engines along with two strap-on solid fuel booster rockets. The vehicle was launched vertically like a space rocket. The largest structure attached to the American Space Shuttle at launch was a huge external fuel tank that carried fuel for the shuttle's three integral rocket engines; these three integral engines were in continuous operation till the Space Shuttle reached orbit in outer space, hence the need for a large amount of fuel[8]. The two strap-on solid booster rockets were jettisoned after use and returned to splash down in the ocean with parachutes slowing down the impact speed. The solid fuelled booster rockets were meant to be recovered from the sea and refurbished for reuse.[9] The entire Space Shuttle returned to Earth through a glide landing and was reusable.[10] The huge external fuel tank was, however, discarded after use. Some national security requirements were also included in the Space Shuttle design to meet needs of the US military[11]. Despite only the external fuel tank being totally expendable the US Space Shuttle did not meet its objective of making space launches less costly. The development and operating costs of the American Space Shuttle were still quite high. The cost of launching a kilogram of payload to space into low earth orbit (LEO), at an altitude of about 330 to 430 kilometers above mean sea level (AMSL) where the International Space Station (ISS) orbits the earth using various space launch methods available to the US were reported as listed at Table 1.

Table1: Cost of Launching a Kilogram to Space for USA

Type of space launch vehicle	Space Shuttle	Russian Progress Spacecraft	US Civil Contractors such as Space X (with Falcon rockets) and now also Blue Origin (with the Shepard rocket). These are still in development phases.
$ cost per kilogram of payload carried to the ISS in LEO	46,789.6	39,927.8	58,894

Source: Subcommittee on Space and Aeronautics Committee on Science, Space, and Technology U.S. House of Representatives, "NASA's Commercial Cargo Providers; Are They Ready to Supply the Space Station in the Post-Shuttle Era?".

The US built five Space Shuttles, these were named Columbia, Challenger, Endeavour, Discovery, and Atlantis[12]. Construction of these craft involved utilisation of high technology ceramic tiles for thermal protection at re-entry into the atmosphere, provision of human habitation space with life support equipment and high end robotics on board to simplify in space mission tasks[13].

Table 1 brings out that the advanced features incorporated in the US Space Shuttle and other overheads involved through the 'cutting edge high technology' nature of the US industrial complex made US Space Shuttle very expensive as a launch system in terms of per payload kilogram (kg) to space terms. The cheapest launch as per the table above is provided by the Russian Progress space craft. These Russian launchers use tried and tested conventional rocket technology of the type used in the 1950s to launch satellites and other payloads by the erstwhile Soviet Union. The development costs of these venerable rockets have been amortised fully and their manufacturing has been made very efficient and reliable. There has been a thread of opinion in various circles that the path towards lower cost access to space lies not in developing reusable launch vehicles but in building robust, well understood, tried and tested rockets that can be mass manufactured cheaply. While there is merit in this argument, especially if one goes by the data placed at Table 1 above, simple rockets do not offer the flexibility of a reusable launch platform. The erstwhile Soviet space program was working on developing the Buran, their version of a Space Shuttle when the Soviet Union was dismantled and a funds crunch forced the project to be abandoned[14]. China is known to be developing its own recoverable space plane development craft called the "*Yuanzheng*-1" or Project 921-3[15] .

Another Path to Launch Cost Reduction

Meanwhile, there are two private companies in the US - Space X[16], founded by the entrepreneur Elon Musk of Tesla and Hyperloop fame[17], and Blue Origin, founded by Jeff Bezos of Amazon.com fame - that are working on an alternate path towards reducing space launch costs. Both these private companies are trying to make conventional space rockets reusable to reduce costs. Space X is trying to make at least some stages of its Falcon rockets reusable by 'soft-landing' the first stage of its Falcon rockets on a floating platform at sea[18]. Space X has also made its rocket as simple as possible by using a single type of engine for all stages, similar materials and designs for all stages, etc. thus reducing design and manufacturing costs while also reducing complexity and increasing reliability`.[19] Two such soft landings of the Falcon first stage have been successfully achieved at sea in addition to several successful landings on land as on date.[20] These hold out hope for appreciable launch cost reductions in future. Blue Origin on the other hand has demonstrated a launch and soft landing of its entire 'New Shepard' rocket. The basic approach is very similar in both cases, but with a few important differences. The Falcon rocket rises to above 124 miles (about 198 kilometers) AMSL, which altitude falls in outer space or above the Karman line.[21] Need to reach such altitudes dictate a taller and more slender design. Blue Origin, on the other hand, rises to about 62 miles (about 99 kilometers) AMSL, which is just about till the Karman line. This allows for a more compact and robust design overall. Falcon also requires, due to the altitude it rises to, moving away from the absolute vertical (with respect to the Earth's surface) as it climbs higher, making vertical landing orientation and stabilisation of its recovered stages more complex to control. The Blue Origin remains vertical throughout its flight, thus somewhat reducing the sensing and control needs for a successful landing. Blue Origin aims to make an entire near space altitude capable rocket reusable while Falcon aims to reuse at least the first stage of a rocket able to take payloads to outer space. All these differences between the Falcon and New Shepard rockets apart, both systems have the soft landing and reuse of rocket stages in common unlike the Space Shuttle that landed a winged orbiter. Through the process of overall simplification followed by Space X, it is likely that the combination of simplification of design and manufacture, and reusability of recovered stages could reduce launch costs. Blue Origin's 'New Shepard' aims to be fully reusable, but does not go above the boundary of space.

A note of caution is needed here. Recovering a rocket stage or an entire rocket by use of the technology demonstrated by Space X and Blue

Origin could have serious drawbacks. Firstly, such recovery requires very accurate sensors to sense the vertical orientation of the rocket stage / rocket. These inputs require to be fed to a high powered computer that can generate required control signals to correct any errors in vertical orientation. Thereafter, the braking force to ensure a soft landing requires the rocket motor to be restarted and its thrust carefully calibrated to achieve a soft landing. The sensors and computing power on board to achieve these ends are likely to be complex and costly. Then there is the issue of leaving adequate unburnt / unconsumed fuel on board the rocket stage / rocket to achieve vertical orientation correction as well as braking for landing. This fuel would limit the payload or lifting power of the rocket, thus restricting the weight of payload it can place in orbit. These complications could detract from the commendable high technology results already demonstrated by both Space X and Blue Origin. The gains in reduced launch cost through soft landing and reuse of rocket stages could be less than initially expected. This is because there are penalties in terms of lesser usable rocket fuel due to some fuel on the rocket being required for the soft landing of the rocket stage(s).

An alternative means of recovering the used stages of a rocket is through utilisation of parachutes coupled with rapidly inflatable balloons. Parachutes affixed to the upper end of the stage could help slow down the impact speed on landing while rapidly inflatable balloons placed at several locations around the stage could cocoon the stage in a bubble of air cushioning to prevent damage during its landing. Such stages could be refurbished for reuse. The parachute and balloon combination method would not require fuel being left unburnt and hence would not compromise on payload carriage. It would also not require complex sensor and control mechanisms when compared to the retro-rocket soft landing techniques demonstrated by Space X and Blue Origin. There are, however, other limitations of parachute recovery systems that could reduce their efficiency. These limitations are beyond the scope of this article. China is reported to be considering a very different method to recover rocket booster stages[22]. The Chinese reportedly intend to fix paraglider like wings to the booster stage. Such wings could deploy after rocket engine burnout and help the stage to glide to a soft landing[23]. However, till date there is no report of this method having been practically demonstrated.

Indian Efforts to Further Reduce Launch Cost

Indian Space Research Organisation (ISRO) has demonstrated its frugal engineering and innovative application of science capabilities several times over the years. These demonstrations have been written about on this website in relation to ISRO's Mars Orbiter Mission (MOM), and Chandrayaan-1 mission amongst others.

ISRO already offers space launches at world beating rates of $ 20,000/- per kg for 1000kg to GTO on the PSLV, $16,000/- per kg to GTO for 2.5 tons to GTO on GSLV, and hopes to reduce these to $ 10,000/- per kg for 10 tons to LEO and 4 tons to GTO on the GSLV Mk-3. The GSLV Mk-3 is still to be fully developed and declared fully operational for commercial launches [24].These launch costs, though they date back to 2012, are still appreciably lower than the launch costs offered by other space launch services as seen earlier at Table 1. ISRO's launch costs to LEO are reported to already be about 60 per cent lower than rates of other launch providers or as low as $ 5000/- to $10,000/- per kg[25]. ISRO, however, is trying to lower launch costs even more through development of a reusable launch vehicle.

The Reusable Launch Vehicle- Technology Demonstrator (RLV-TD)

ISRO carried out the first technology development test of its reusable launch vehicle-technology demonstrator (RLV-TD) on May 23, 2016. It has chalked out a step by step procedure to develop and prove the technologies required for the RLV. The first test flight on May 23, 2016 was called the Hypersonic experiment (HEX). This test involved development of a winged hypersonic speed capable craft, the RLV. ISRO built a scaled down test vehicle modelled on its Aerobic Vehicle for Transatmospheric Aerospace Transportation (AVATAR) concept[26]. AVATAR is designed to eventually be a single stage to orbit (SSTO) craft. ISRO has identified key technologies needed to develop AVATAR and is testing them in a staged manner. Hence the first RLV-TD was aimed at testing just a few key parameters. These are as below:-

- The hypersonic flight (hypersonic glide in this first experiment) characteristics of the RLV design[27].
- The performance of the heat shield system developed for RLV for the re-entry to the atmosphere phase of flight.
- The RLV's guidance system for it to reach a pre-determined geographical location autonomously after re-entry into the atmosphere.
- RLV's control system and its ability to steer the craft accurately.
- Landing (on the sea surface in mission RLV-TD1).

ISRO is ecstatic in that all the set mission test parameters in mission RLV-TD1 have been successfully achieved[28].

RLV-TD1 was launched in a Two Stage To Orbit (TSTO) configuration with a HS9 solid fuel booster rocket carrying it to an altitude of 56 km AMSL. At this stage the RLV separated from the booster and rose further to 65 km AMSL. Thereafter the RLV entered the atmosphere, achieved glide at a speed of about Mach 5.0 and navigated to the predetermined geographic location in the Bay of Bengal[29]. The RLV then landed on the water and floated for some time. The RLV was not recovered in this mission, but was abandoned to sink at sea. Telemetry data has been collected to assist in the next phase of the test program[30].

The next development test flight of RLV is planned in the next two to three months. The proposed phases in technology development and testing are as below:

- Landing Experiment (LEX). In this the RLV will be required to land on a runway. For this test RLV will be fitted with an undercarriage and will glide to land like an aircraft.[31]
- Return Flight Experiment (REX). This test involves RLV being fitted with engines to take off like an aircraft and to land like an aircraft under its own power.[32]
- Scramjet Propulsion Experiment (SXPEX). This test involves fitment of the scramjet engine being developed by ISRO underneath the RLV. The RLV will, after achieving high supersonic speeds, engage the scramjet to accelerate further and prove the scramjet technology before it is recovered[33].

Potential Gains for India from the RLV-TD Program

At present the RLV is a technology development and demonstration project to develop and prove technologies that can be used elsewhere. RLV is not designed to enter outer space in the way that the US Space Shuttle did. It is designed to reach close to or slightly above the Karman line and from there to loft satellites into space while itself returning to Earth for reuse. This plan in itself helps to reduce costs and complexity. In addition, as far as is known, the RLV is not designed for manned flight, again reducing costs and complexity. The RLV is likely to remain a TSTO vehicle.

These design decisions by ISRO for the RLV are likely to make it possible for ISRO to meet its target of reducing its satellite launch cost to one tenth of the current costs achieved with expendable rockets such as PSLV etc. However, there is much more to the RLV-TD program and its benefits.

The technologies being developed and tested in the RLV-TD program have potential for utilisation in several different areas. Firstly, the possibility of ISRO achieving a globally leading position in operationalising a SSTO craft, the AVATAR, is there in case all the planned test flights of the RLV-TD program are successful. This, if achieved, would place ISRO and India as the leading space technology player by a wide margin. In the public domain, only the UK with its Skylon project, powered by its Synergistic Air-Breathing Rocket Engine (SABRE) engine[34] is attempting to develop a SSTO craft, apart from ISRO. All other known launch vehicles in the world are either legacy expendable rockets or TSTO like the US XC-37 and Chinese *Yuanzheng-*1. It is evident that AVATAR, if developed, will be very different from the RLV. However, some of the technologies being tested in the RLV-TD program are likely to find application in AVATAR.

Apart from the prospects for AVATAR, the RLV-TD program is planned to prove technologies such as thermal insulation for re-entry into the Earth's atmosphere, applicable for use in a future Indian manned space program. Hypersonic glide vehicle design technology has potential utilisation for improving Indian ballistic missiles' Ballistic Missile Defence (BMD) penetration capability. Manoeuvrable hypersonic glide capable ballistic missile warheads could help increase penetration of BMD system defended airspace.

Autonomous guidance and control capability could find use in unmanned craft designed and built in India. This could also be used for very long range accurate weapon delivery.

RLV through its use of solid fuel HS-9 boosters could reduce the lead time for launching payloads into space. This could have beneficial national security implications for India.

Hypersonic glide and scramjet engine technology could also find application in military projects involving high speed aerospace craft in future.

It is quite evident that ISRO has again embarked upon a cutting edge technology development program. This program is being developed, as has been the case with all Indian space projects, for application in the civil field of space research and satellite launch. However, with the increasing utilisation of space technology for national security purposes and the increasing convergence between air craft and space craft towards true aerospace craft, the technologies being developed by RLV-TD could find application in myriad other fields including military technology.

Conclusion

ISRO has made giant strides in its capabilities over the past few years. After developing its workhorse PSLV rocket it has gone on to develop more powerful rockets such as GSLV and its improved variants, the GSLV Mk-2 and GSLV Mk-3. In the process, ISRO has already achieved very low launch costs in terms of per kilogram to orbit as compared with other more advanced space agencies. ISRO has nonetheless formulated a program to reduce its launch costs to one tenth of current costs. Towards this end it has embarked upon its TSTO RLV-TD project. Similar cost reduction projects in the past, such as the US Space Shuttle, failed to attain lower launch costs. ISRO has deliberately kept its RLV simple and robust enough to achieve the cost reduction objective. Current US launch cost reduction efforts are directed towards developing reusable rockets as demonstrated by Space X with the Falcon rocket and Blue Origin with the New Shepard rocket. ISRO's RLV-TD could lead to development of ISRO's SSTO AVATAR spaceplane. The new technologies being developed and proved in the RLV-TD program have several potential uses in India's civil space program, as well as in the military field.

Given its proven track record ISRO appears well poised to achieve even greater heights. The progress ISRO makes in new technology development are likely to have several beneficial spin offs for India.

(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

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