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India's Mars Mission: Multidimensional View

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Over the years, Mars has been the centre of attraction for science fiction writers, Hollywood movie makers, astrologers, astronomers and the scientific community. For scientists and technologists, Mars continues to be an enigma. This is essentially because even tough humans have dreamt for long about human colonisation of Mars. Still, in reality humans are nowhere near to realising such a dream. During the last five decades, more than fifty percent of human efforts to send an unmanned spacecraft to hover in the vicinity of Mars or to land on the Martian surface have failed. Interestingly, during September 2014 a developing state like India succeeded in placing its own satellite in the Martian orbit and that too in its first attempt when no other state was able to achieve such distinction in all these years. India's success has won significant international acclaim and has significantly raised expectations about its overall space programme. This paper attempts to understand the rationale behind India's Mars agenda and its implications and discusses its progress towards success.

From the beginning, developments in space science and technology have witnessed the dominance of major powers. Today, when India's strategic vision for outer space is being appreciated globally, a query is raised on these lines: 'How a state like India, operating in a

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complex regional environment and fighting various internal socioeconomic-development-related challenges, was able to afford an unwavering politico-economic commitment towards sustaining its space agenda for more than four decades?' There is also curiosity to know why India wants to reach Mars. There is also an interest to know about the involvement of foreign powers behind India's overall success in the space sector. This paper has four major sections. The first section puts in context India's Mars agenda in the backdrop of its overall investments in the space arena. The second section describes the Mars mission in totality. The third section debates the budgetary aspects, and the last section dwells on the politico-economic advantages of this mission.

A Fragment of India's Space Agenda

Indian space programme had a very humble beginning during the early 1960s. India launched its first satellite in 1975 with assistance from the erstwhile USSR. India achieved the status of space-faring nation[2] by 1980, and by the end of 2014 has launched around 75 satellites. India's vision for a space programme was articulated by Vikram Sarabhai during late 1960s. He had said that India's space programme would be a civilian programme with focus on application of space technology as a tool for socioeconomic development of the country.[3] The Indian Space Research Organisation (ISRO), the agency responsible for evolving and implementing India's overall space agenda, was established on 15 August 1969. Appreciating the importance of the space domain, it was placed under direct supervision of the prime minister. An exclusive Department of Space (DOS) and the Space Commission were set up in 1972. Satish Dhawan as Chairman of ISRO (1972-1984) during its formative years was instrumental in developing scientific temperament, professionalism and work culture in the organisation.

Indian investments in satellite technologies have mostly been in the field of meteorology, remote sensing and communications. Presently, India's Remote Sensing (IRS) satellite network with eleven operational satellites is the largest civilian remote sensing satellite constellation in the world. The data inputs from these satellites are used for several applications covering agriculture, drought and flood forecasting, management of water and ocean resources, urban development, mineral prospecting, forestry, and disaster

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2 A nation with an indigenous capability to design, develop and launch artificial satellites as well capabilities to monitor and control their activities with appropriate ground infrastructure.

3 Sankar U, *The Economics of India's Space Programme*, New Delhi: Oxford University Press, 2007, pp.1-2.

management.[4] India is also developing its own navigational network called Indian Regional Navigation Satellite System (IRNSS). This seven-satellite system is expected to be fully operational by 2015-16 and would provide a better than 20 m position accuracy.

For many years, the main pivot for Indian space programme has been its most successful satellite launching system called Polar Satellite Launch Vehicle (PSLV) which could launch satellites weighing less than two tonnes in polar orbit, and approximately one-tonne-satellite into the geosynchronous transfer orbit. Till October 2014, there had been 27 successive and successful flights of PSLV; and this system has also been used commercially to launch satellites for the client states. However, the basic limitation of Indian space programme is the lack of ability to put heavier payloads (say four tonnes and more) into the geostationary orbits. Due to this, India has to rely on hiring launching services for heavy satellites, say from agencies like the French company called Arianespace.

For all these years, ISRO has ensured that the lack of heavy-lift launcher would not stall the growth of the space programme; where possible ISRO has devised innovative approaches to overcome the lack of indigenous heavy-lift capabilities. Since 2005, ISRO appears to have started following a two-pronged strategy: concentrating on developing a heavy-lift launch vehicle (GSLV-Geostationary Satellite Launch Vehicle) and simultaneously addressing new areas in space research. During November 2006, Indian space scientists and technologists held a brainstorming session where ideas like the Moon- and Mars-missions and human space missions were discussed. This session was held on the recommendation of the then Prime Minister Manmohan Singh.[5] Subsequently, during October 2008 India launched its first mission to the Moon called Chandrayaan-1 satellite—to revolve around the Moon with 11 scientific instruments on board. This mission marked a major success, with Indian scientists along with their US counterparts discovering the presence of water on the Moon. ISRO realised that the infrastructure created for the Moon mission could also be used/modified for undertaking other similar Deep-space missions.[6] After the successful completion of the first mission to the Moon, ISRO's interest in Mars should be seen as a continuation of its Deep-

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4 www.isro.org/satellites/earthobservationsatellites.aspx.

5 K. S. Jayaraman, "India's Space Agency Proposes Manned Spaceflight Program", Nov 10, 2006, www.space.com/3098-indias-space-agency-proposes-manned-spaceflight-program.html, accessed on 28 October 2014.

6 There is no structured definition of deep space. However it, at times, gets discussed as a region outside of the Earth's atmosphere. Also, some view this as a region covering the distance of one million-two million km from the Earth's surface.

space agenda. A brief glance at various missions undertaken by ISRO since 2010 indicates that they have many programmes under simultaneous development. Various activities have taken place during the last four to five years in the development and launch of meteorological, remote sensing and communications satellites. Indigenously-developed cryogenic engine was successfully tested during this period. Also, India's satellite navigational system is in the making. A few commercial missions were undertaken and India's first military satellite GSAT-7 was developed and launched during the same time. The Mission to Mars is one element of this comprehensive space agenda.

Mars Orbital Mission

India's Mission to Mars was launched on 5 November 2013. The official announcement in regard to India's plans to launch this mission was made by Manmohan Singh during his Independence Day speech on 15 August 2012. Officially, the Indian mission, called the Mars Orbital Mission (MOM).[7] The spacecraft successfully entered the Martian orbit on 24 September 2014 after 298 days of travel. The correct entry into the Martian orbit has been a challenge for various states that have reached Mars or have attempted to reach Mars.[8] Presently, India is the only state that has succeeded in reaching the Martian orbit in the first attempt.

This is India's first interplanetary mission. It needs to be highlighted that the expanse of this mission is rather limited in comparison with the missions executed by the US or the European Space Agency (ESA). India's mission is an indigenous effort and has been designed with a limited mandate. The basic limitation for ISRO while designing this mission arose from the non-availability of a heavy-lift launch vehicle. Presently, India's launching capability is restricted because the GSLV is not yet fully operational. Naturally, to undertake a mission to Mars, India was compelled to design a mission with a very limited payload, because using the PSLV was the only option. The limitation was that the PSLV could place a satellite only in geocentric and low-Earth orbit. It may be noted that during same period, NASA had launched its mission to Mars called MAVEN (Mars Atmosphere and Volatile EvolutioN Mission) and this satellite had left the Earth's atmosphere immediately after the launch, so MOM had to

[7] It may be noted that informally this mission is popularly mentioned by the name Mangalyaan which in ancient Indian language called Sanskrit means a craft to Mars. Probably, since India's Moon mission was officially called Chandrayaan (craft to the Moon) the mission to Mars has been called Mangalyaan.

[8] Before MOM and MAVEN, of the 22 Mars orbital missions attempted by different countries, only nine were successful.

wait for its exit for 25 days. ISRO scientists had worked over this limitation of PSLV by an innovative mechanism where seven altitude-raising orbital manoeuvres were designed and executed with precision, and on 30 November 2013, MOM left the Earth's orbit.[9] During the fourth manoeuvre, ISRO faced difficulty and was not able to achieve the required altitude. However, within 24 hours a 'correction' was carried out by undertaking an additional manoeuvre.[10] Subsequently, MOM was put in the heliocentric orbit and travelled for nine months to reach Mars. During this period, there was much concern about the danger of solar radiation impacting the satellite. However, the 'skin' of MOM was able to withstand such radiation and made perfect progress towards Mars. It was expected that during such a long-duration and lengthy travel, MOM might deviate from the programmed path. To correct any such deviation, a series of trajectory correction manoeuvres was planned. Four such operations were planned. However, only three were carried out because the spacecraft was mostly travelling along the programmed path.

The most crucial aspect of the entire mission was a precise entry into the Martian orbit. There was a major concern about the performance of liquid apogee motor (LAM). This was because the LAM was to remain non-operational during MOM's travel in the heliocentric orbit and was expected to restart after a gap of almost 300 days. To enter the Martian orbit, the velocity of MOM was required to be reduced significantly. Hence there was a requirement to restart the engine by operating LAM after a gap of almost 300 days. To guard against any failure towards restarting the engine, ISRO had provided a set of parallel circuits for the propellants' flow-lines and redundancy in the form of a latch-valve. ISRO had a plan "B" in place. In the event LAM failed to fire, ISRO would attempt a Mars orbit insertion using the eight 22N thrusters'.[11] The mission progressed as planned. MOM made a perfect entry in the Martian orbit and started taking observations. ISRO has established a telemetry, tracking and command network (ISTRAC) for overall monitoring of the mission. For the purposes of the Moon mission, the Indian Deep Space Network was established during 2007/08. It is a key

9 The altitude was raised from an initial apogee of 23,500 km on 5 November 2013, in several phases, to 1,92,874 km on 15 November, and subsequently heliocentric insertion was carried out on 30 November 2013.

10 The fourth manoeuvre on 10 November 2013 was expected to raise the apogee to more than 1,00,000 km. However, an additional manoeuvre was required on 11 November to raise the apogee to 118,642 km as planned.

11 http://isp.justthe80.com/planetary-exploration/mars-obiter#TOC-Mid-Course-Trajectory-Corrections-Maneuvers-TCMs-, accessed on 2 November 2014.

centre for Mars mission too. ISRO also obtained position data from NASA's Deep Space Network stations located in Canberra, Madrid and Goldstone on the US West Coast.[12]

Various payloads were designed and developed by ISRO scientists for this mission. However, only five[13] payloads could be accommodated on MOM. The weight of these five payloads is around 15kg. As explained by ISRO, the main purpose of the mission is to learn how to reach Mars. However, they do have well-articulated scientific objectives as well. The MOM was designed to last for six months. There is a possibility that this mission could last longer. These sensors are designed basically for two main purposes: one, to find out more about the Martian atmosphere (lack of it), and two, to know about the possibility of detecting the presence of methane on Mars and its origin (is it biological?). Not only India but the entire world is keen to know about the possibility of life on Mars. The methane sensor on board MOM could play a major role towards obtaining this knowledge. Any presence of methane on Mars could provide some clue about the possibility of microbial life out there. The atmospheric sensors are expected to help in the understanding about how the planet lost the bulk of its atmosphere billions of years ago. Also, there is a sensor to identify the nature of minerals available on the Martian surface.

A Budget Mission

Since India announced its Mars mission, there has been much debate both internationally and domestically, primarily on following issues:

- What was need for a developing country like India to 'waste' money on such a mission particularly when the state faces various challenges like poverty, shortage of clean drinking water, lack of sanitation facilities etc.?
- How could India manage such a low-cost mission?
- How is it possible to put the mission in place in such a short time?

Normally, it is believed that India began the preparations for the mission from the time it was announced officially (announcement on 15 August 2012 and the mission took off on 5

[12] "India to enter Mars orbit on September 24", *The Hindu*, 22 September 2014.

[13] The payloads on board MOM are Mars Exospheric Neutral Composition Analyser (MENCA), Thermal Infrared spectrometer, Lyman-alpha photometer, Methane Sensor and Colour Camera.

November 2013). However, it needs to be appreciated that no country would officially announce the mission unless its scientific community gives the political leadership an assurance that it has already done the groundwork for such a mission and is confident of the wherewithal to undertake such a mission. Also, normally, the leadership of any state waits for an opportune moment to make such major proclamations. India’s Prime Minister made the official announcement on the country’s Independence Day. It is important to note that in just over a month’s time, on 21 September 2012, the Hindustan Aeronautics Limited (HAL), India’s public-sector aerospace organisation, handed over the satellite structure for the Mars Orbiter Mission to ISRO.[14] This clearly indicates that work on the mission had begun before the official announcement of the mission.

India's "Mars strategy" was briefly articulated in 2007 by the-then Chairman of ISRO, G Madhavan Nair. He had announced that ISRO was studying a proposal on a mission to Mars and was confident of undertaking a trip to the Red Planet within five years of the government giving the required permission.[15] India was expected to launch its second mission to the Moon in collaboration with the Russians around 2012. However, this mission was significantly delayed and is now likely to happen around 2016/17 as a standalone Indian mission without any help from the Russians. Probably, this delay allowed ISRO to divert some of its resources to study Mars. It was also important to put a mission in place quickly because the launch window was available around end-2013 considering the longer travel time of nine months to Mars. The distance of Mars from the Earth varies significantly owing to the nature of orbits of motions of these planets, and only after every 26 months Mars comes closest to the Earth. Such an opportunity was available around September 2014.[16] It is difficult to pinpoint the exact date of start of India’s mission to Mars. However, it could be safely concluded that ISRO would have had a maximum of two-to-two-and-a-half years to plan and execute the mission.

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[14] The satellite structure is an assembly of composite and metallic honeycomb sandwich panels with a central composite cylinder. Also, as per HAL they had also delivered seven types of riveted structural assemblies and four types of welded propellant tankages for the Polar Satellite Launch Vehicle (PSLV-C25). “HAL’s ‘hand’ in Mars mission”, *The Hindu*, November 6, 2013.

[15] 'ISRO studying proposal on mission to Mars', *Times of India*, April 11, 2007, available on http://timesofindia.indiatimes.com/india/ISRO-studying-proposal-on-mission-to-Mars/articleshow/1894649.cms, accessed on 30 October 30, 2014.

[16] The minimum distance from the Earth to Mars is about 56 million km and the farthest distance could be about 400 million km. In 2014, Mars came as close as around 92 million km to Earth. In 2016, it is likely to come as close as about 75 million km and in 2018 it would be around 58 million km.

Based on the yearly Budget figure announced by the Government of India, it becomes obvious that the provision of money for this mission began in 2012. There was no expenditure on this mission as of March 2012. At the beginning of the project, the total estimated cost was Rs450 crores (approximately US$75 million; one crore is ten million). The budgeted money for the 2012-2013 cycle was Rs125.00 crores; and for the cycle 2013-2014, it was Rs167.50 crores.[17] For the year 2014-15, Rs.65.93 crores have been allotted. Overall the money demanded and allocated to ISRO so far for this mission is approximately Rs360 crores. This indicates that the entire cost of the mission could be lesser than the projected cost.

There has been much debate about how ISRO has achieved the feat of keeping the cost of this mission so low. To put the issue in perspective, it is important to have some comparison with other global missions. Approximately, ISRO's total budget is US$1.2 billion per year, while that of NASA is about US$17.5 billion. With regard to the mission to Mars, NASA's mission called MAVEN, could be broadly considered to be in the same generic category (it is understandable that it is a heavier satellite and has more payloads etc) than MOM,[18] However, the cost differential is very high. MAVEN's cost is US$671 million against the MOM's cost of US$75 million. The European Space Agency's (ESA's Mars Express Orbiter has a price tag of approximately US$386 million. The Team NASA was working on the MAVEN for a minimum of five years while the making of MOM probably took about two years.[19] It is obvious that if India was to undertake a mission similar to MAVEN, then it would have definitely cost far less.

ISRO scientists have succeeded in keeping the costs down by using "novel" approaches. Over the years, Indian space programme, as far as possible, has followed the path of indigenisation owing various reasons including necessity. This is essentially due to India's nuclear policies. India has conducted nuclear tests. For many decades, there was a significant absence of international collaboration owing to India's nuclear policies and the tests it had undertaken in 1974 and 1998. In response to these tests, the rest of the world had put India under technology sanctions regime, limiting India's access to sophisticated technology. Naturally,

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[17] www.isro.org/pdf/Outcome%20budget2013-14.pdf, accessed on 23 August 2014.

[18] MAVEN is on a one-year mission while MOM has mission span of six months. MAVEN is observing Mars from a much nearer distance than MOM and has more payloads. MAVEN has a wet mass of 2,550 kg and a dry mass of 717kg while MOM has a wet mass of 1,350 kg and a dry mass of 500 kg.

[19] http://economictimes.indiatimes.com/slideshows/science-technology/why-isros-mars-mission-is-the-cheapest/isros-mars-mission-the-cheapest/slideshow/24982329.cms, accessed on 14 October 2014.

India had no option but to develop technologies on its own. Also, being a developing state, the Indian scientific community had limited budget available to undertake research and development. All these have taught the Indian scientific community to develop technologies in a cost-effective manner and to try to 'manage' within the available resources.

The low cost of MOM is a combined result of various factors. Chiefly, ISRO had a number of constraints owing to the lack of availability of a heavy launcher system. Interestingly, the absence of such a launcher has actually helped to cut costs. Fewer scientific sensors were put on board MOM due to weight limitations. MAVEN had a powerful rocket booster which allowed the spacecraft to be placed in a higher orbit while MOM was launched using PSLV at a much lower altitude. Subsequently, MOM went around the Earth, and the spacecraft's orbit was raised by using a propulsion system. Agencies like NASA or ESA normally make three physical models of the systems which are to be launched. ISRO depended more on 'virtual' models, essentially software-developed tools, than making actual working models. Also, there are differences in testing procedures. All these directly or indirectly contributed towards the cost reduction.

The key factor for effective cost-savings on ISRO's various programmes its policy of continuity with its launch vehicle ISRO attempts to use its proven technology as the base for future development. ISRO has mainly followed a modular approach,[20] like developing variants of PSLV depending on the requirement of a specific mission. In fact, ISRO's next-generation vehicle in the making, the GSLV, is also an expansion of the PSLV, with a cryogenic engine juxtaposed on it. The ground infrastructure for Mars mission is also an expansion of the ground segment that was designed and developed for the 2008 Moon mission.

The work culture in ISRO allows for aggressive scheduling. For the Mars mission, ISRO first made the entire blueprint based on available resources, and no attempts were made on research for new techniques/technologies, particularly like designing and building a completely new rocket specifically for this mission. A small but dedicated team of ISRO scientists worked on this mission (they even work 18 to 20 hours a day depending on requirements while major space agencies normally follow a 35-hour work-week cycle). Also,

[20] Saritha Rai "How India Launched Its Mars Mission At Cut-Rate Costs", http://www.forbes.com/sites/saritharai/2014/10/19/fifty-years-after-the-bullet-train-japan-approves-plan-to-build-super-speed-maglev-train-line/, November 05, 2013, accessed on 20 December 2013.

it is important to note that comparatively low salaries in India do contribute towards the overall cost reduction. India's rocket-scientists get paid on par with various other government officials. The scientific manpower available in India comes at a much reasonable cost than in other parts of the world. ISRO pays its mid-level scientists around US$ 1,500 to 2,000 per month while the monthly salary of NASA's scientists is about US$6,000 and its top rocket-scientists get more than US$10,000 per month.[21]

Essentially, ISRO has practised frugal innovation – approach that consumes minimal resources, yet yielding the desired results. Over the years, ISRO has been designing inexpensive products and manufacturing them with little capital. The cycle from concept-to-proof of an idea is quick[22] and MOM is just a continuation of this process.

It is crucial to appreciate that the chief mandate for ISRO since its inception has been indigenous technology development. Hence, Mars mission's use of indigenously developed technologies. In the beginning, ISRO started the process of indigenisation by developing and establishing an earth station during the 1970s. The biggest challenge for ISRO was to develop the launcher technology. ISRO experienced some failures in this field but finally succeeded in 1980 by injecting Rohini satellite using the SLV-3 rocket. With this, India had joined the select group of five countries in the world to possess its own launch vehicle capability. This helped ISRO to derive major technological benefits in multiple areas, from development of high-energy solid propellants to the development of carbon composites, precision fabrication and thermal protection etc.[23] This process of indigenous technology development continues till date, and over the years ISRO has succeeded in developing a range of technologies from remote-sensing satellite systems to cryogenic engines. For Mars mission, the main focus of ISRO has been to use the existing technology base innovatively and carry out improvisation where necessary. Only a few specific technologies were required to be developed for this mission. Particularly, for LAM to restart after a gap of 300 days, new pressure-regulator

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[21] http://nasajobs.nasa.gov/default.htm, accessed on 2 November 2014, and Scott Neuman, "Why India's Mars Mission Is So Much Cheaper Than NASA's", November 5, 2013, http://www.npr.org/blogs/thetwo-way/2013/11/04/243082266/why-indias-mars-mission-is-so-much-cheaper-than-nasas, accessed on 22 February 2014.

[22] Arun Sahay, "India's Mars Orbiter Mission: The frugal innovation", October24, 2014, *The Financial Express.*

[23] U R Rao, *India's Rise as a Space Power*, Foundation: Delhi, 2014, pp. 12-13, 76-78, 130.

projection and isolation mechanisms were specifically developed.[24] Also, various sensors on board MOM have been specifically designed and developed for this mission.

From the announcement of the Mars mission to its successful completion, there has always been an undercurrent of scepticism, both domestically and globally, about how a state like India, dogged by issues related to poverty, could indulge in ‘unwarranted (?)’ expenses like those on a Mars mission. Probably, this notion emerges from the supposition that space-faring is a game for the rich and powerful states. Historically, it has been observed that since the beginning of the space era (1957, launch of the first satellite Sputnik by the erstwhile USSR) and particularly during the Cold War period, space has been viewed as a medium of competition amongst the superpowers. However, it is important to realise that India joined the space club because of the realisation that space has tremendous utility for the socioeconomic development of a state and even today, India considers space as a medium for social development.

Broadly, Indian investments in the Deep Space arena consumes around 2% to 5% of ISRO’s yearly budget, and the cost of the Mars mission is about 0.01% of the country’s overall annual budget.[25] The people opposing India’s Mars programme argue that the same money would be better spent on healthcare, drinking water and better sanitation – without realising that India has the biggest remote-sensing programme in the world which is used for land-water resources planning, and India’s communication satellites assist the medical fraternity to effectively implement the telemedicine programme. The entire cost of India’s mission to Mars is almost the same as buying one medium-size passenger aircraft or figuratively lesser than any Hollywood blockbuster movie. For example, the cost of the movie Gravity was around US$100 million against the MOM cost of US$75 million. Presently, India is the world’s third biggest economy in terms of purchasing power parity.[26] Against this backdrop it could be immature to criticise India for investing in science and technology with a long-term vision.

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[24] Ajey Lele, *Mission Mars: India’s Quest for the Red Planet*, Springer: New Delhi, 2014, p.117-118

[25] Laxman S, *Mars beckons India*, New Delhi: Vigyan Prasar, 2013, p.5.

[26] http://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD/countries/order%3Dwbapi_data_value_2013%20wbapi_data_value%20wbapi_data_value-last?order=wbapi_data_value_2012%20wbapi_data_value%20wbapi_data_value-last&sort=desc&display=default, accessed on 6 November 2014.

Assessment

India's space programme has a history of over five decades and its major investments in this sector have been towards the development of telecommunications infrastructure, improvement of environmental monitoring and the use of various satellites to assist agriculture, resources-management, education, medicine and scientific discovery. Appreciating India's requirements in the 21st century, ISRO is presently undertaking a few additional programmes like the development of regional space navigation system etc. India has already made forays in the commercial satellite launch market, and is also selling satellite-derived data, and proposes to significantly increase space commerce. Deep Space is one area where India is investing more for scientific pursuits, and the mission to Mars should be viewed as one aspect of such a quest,

India's Mars mission demonstrates that 'big ideas' are not the prerogative of the developed states alone. ISRO's general philosophy of cost-effectiveness, using short development-cycles, using existing resources judiciously, and leveraging on the existing technology-base have helped go as far as Mars. However, this is just a beginning, and India needs to undertake more missions to unfold the mystery of Mars.

India's investments in programmes like its mission to Mars could be assessed at various levels – from the scientific to commercial to the strategic to geopolitical.

From the scientific point of view, such missions allow long-term building of capacity and capability. MOM is likely to contribute to enhancing the existing knowledge about Mars. This mission has come at a time when two other missions namely NASA's MAVEN and ESA's Mars Express are also observing Mars in almost similar fashion. The data generated by these three missions could jointly help validate or test the earlier understanding of Mars. This should be useful for future missions. Also, the success of this mission would have an impact in attracting young talent to study space science in India. For the last few decades, it was observed that the information technology (IT) revolution in India was encouraging the younger generation to study mostly IT-related subjects, because of the job opportunities there. There is a need to attract the younger generation to study space sciences, aeronautics, aerospace engineering etc.

ISRO-industry relationship has a long history. Since the 1970s, the private industry is a key factor in the growth of India's space programme. Over the years, the Department of Space has nurtured a strong partnership with Indian industries. More than 500 small, medium and large-scale Industries assist ISRO in hardware development and supply, software and other services. Almost 60% of a launch vehicle's cost flows to Indian Industries. Private players play a major role towards the development of the ground segment too.[27] Major industry contributors in the space area are Larsen and Toubro (L & T), Godrej, Tata, Walchandnagar etc. Likewise, public sector organisations like Hindustan Aeronautics Ltd (HAL), Bharat Electronics etc. are involved in various fabrication-related activities.[28] More than 250 industries have contributed towards assisting ISRO in its maiden Mars mission. The success with missions like Mars helps to attract global attention and is expected to bring more business to ISRO. The basic mandate of ISRO is research and development. The increasing expanse of India's space agenda calls for more private investment. Also, there is a need to transfer the technology developed by ISRO to the private industry. Over the years, ISRO has transferred various technologies to the private industry (250 technologies by the year 2000[29]). Probably many of these technologies were meant for the small and medium sector. In order to bring about a "revolution" in the space industry and to allow ISRO to concentrate on research, it is vital to develop the satellite-manufacture-and-launch sector as a private-sector activity.[30] It is important to attract foreign direct investment (FDI) in the space sector. Indian government has allowed 49% of FDI in the defence sector. In the near future, it would be of interest to know the level of interest that the foreign investors evince in the aerospace sector which obviously is 'the' most important constituent of defence industry. However, there should be greater clarity on foreign investments in India's space sector which is essentially a 'civilian' sector. .

India's successful Mars mission marks a great leap in science and technology, innovation and project management. At present it is difficult to ascertain whether such Deep Space missions would bring any direct benefit to India's military. It could be argued that a state learns much with regard to robotics, materials, communication and sensor technologies while undertaking such missions; this knowledge can be utilised for military purposes. However, such

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[27] www.isro.org/pdf/Outcome%20budget2013-14.pdf, accessed on 23 August 2014.

[28] U R Rao, *India's Rise as a Space Power*, Foundation: Delhi, 2014, pp. 187-188.

[29] U R Rao, *India's Rise as a Space Power*, Foundation: Delhi, 2014, p. 187.

[30] There is already a proposal to this effect, and ISRO is planning to transfer the PSLV technology to industry and allow the development of satellite-launching facilities in the private sector. This information is based on the informal conversation by the author with a few scientists.

inferences are 'derivative'; the knowledge of technologies like robotics, communications etc. could be garnered by simpler means, and no mission to Mars is required for such purpose! In the absence of military significance, it should be easier to involve the private industry; India should encourage and assist the private sector to play a major role in future missions to Mars.

There may not be any explicit strategic benefit to India from its 'Martian triumph'. However the subtle strategic impact cannot be belittled. China was 'silent' about Mars after its first attempt had failed in 2010. However, now after the successful Indian mission, some indications are emerging from the Chinese media that China would like to have a mission in 2020 which could be 'better' than the Indian mission. Has India inadvertently (or otherwise) forced China to start a 'race'? It could be premature to talk of a 'race' at this juncture. . However, it is important to note that this success had helped India to change the global perceptions about it from being a state of snake charmers to a technological power for tomorrow. In the coming years, India could do 'business' with the rest of the world not as 'some third world country' but as a state with proven technological credentials.

India is a pragmatic power and does not view space technologies as a tool to undertake symbolic activities and raise the sense of nationalism amongst the population. Indian investments in the Mars mission have a sound technological and scientific logic. The success of this mission – being the first state in the world to enter the Martian orbit with precision in the first attempt, and so far the only Asian state to succeed in this fashion – has definitely raised India's stature globally. These benefits are incidental but important. The benefits from this Mars mission to ISRO and to India should be viewed under 'different prisms'. For the Indian scientific community, this success is more about evaluating indigenous capabilities and about planning accordingly for future missions. On the other hand, India can present itself as a technology-power and as a 'competitor' in the realm of space commerce. It enhances India's prestige and discredits the 'tag' associated with India for a long time: that of a 'developing state'. Overall, MOM shows India's potential to emerge as a 'great power' in the 21st century.

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