9-617-062
REV: JULY 11, 2017

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ISRO: Explore Space or Exploit CubeSats?

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

— ISRO's Vision

To emerge as a globally significant space company fully utilizing the strengths of ISRO and other entities in the field of space.

— Antrix's, ISRO's commercial arm, vision

Late one evening in the winter of 2016, A.S. Kiran Kumar, the chairman of Indian Space Research Organization (ISRO) received a phone call from the US space agency NASA. His American counterparts were calling to congratulate him on ISRO's Mars Orbiter completing two years in orbit. Kumar couldn't help but smile knowing that ISRO's mission had been cheaper—two-thirds the cost—than the Hollywood movie *Gravity* and stayed in orbit 18 months longer than anticipated. However, his thoughts quickly turned to ISRO's future. As he gazed at the starlit sky from his office in Bengaluru in South India, he mused about his meetings earlier in the day.

ISRO had been established in 1969 by the Indian government to address domestic challenges with space technology. By 2016, ISRO was one of the six largest space agencies in the world. Through its 59 launch vehicle missions, ISRO had launched numerous satellites for communication, earth observation, disaster management, navigation, scientific exploration and other diverse purposes. Moreover, its commercial arm, Antrix Corporation, set up in 1992 to launch satellites for domestic and international customers, had cornered 0.6% of the global space launch market. However, requests from both the Indian government and commercial organizations were increasing.

Kumar reflected on his day. In the morning, he had met with Subbiah Arunan, the project director of India's mission to Mars, who had proposed a $90 million follow-up mission. Arunan had lofty scientific ambitions for the mission that came with significant technological challenges. In the afternoon, he had met Rakesh S, the CEO of Antrix, who briefed Kumar on a potential new client, a Silicon Valley technology firm that planned to set up a broadband communication network using a constellation of small satellites. He had also received a phone call from a senior government official checking on plans to launch new satellites to serve disaster management efforts and the Indian direct-to-home (DTH) industry. The back-to-back meetings left Kumar thinking about where to focus ISRO's

Professors Prithwiraj Choudhury, Tarun Khanna, and Karim Lakhani and Associate Director Rachna Tahilyani (India Research Center) prepared this case. It was reviewed and approved before publication by a company designate. Funding for the development of this case was provided by Harvard Business School and not by the company. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

future efforts. The revenue potential from Antrix was hard to ignore, especially considering ISRO's modest government budget. However, as the head of a scientific organization, Kumar was committed to the pursuit of science. The success of the Mars Orbiter had unleashed a nationwide celebration and an encore achievement was expected. Finally, Kumar needed to consider ISRO's mission to serve the nation and was well aware of the capacity constraints of ISRO's current launch pads.

History of India's Space initiative and ISRO Today

In 1962, five years after the launch of Sputnik, the world's first artificial satellite, India initiated its space program by establishing Indian National Committee for Space Research (INCOSPAR) with Dr. Vikram Sarabhai at its helm. INCOSPAR pioneered many initiatives such as establishing the Thumba Equatorial Rocket Launch Station for upper atmospheric research and setting up a space science and technology center to study the development of systems and components for launch vehicles. (See **Exhibit 1** for some key milestones in ISRO's history.)

On August 15, 1969, India's 22nd anniversary of independence, INCOSPAR gave way to the Indian Space Research Organization (ISRO). The live telecast of the 1964 Tokyo Olympic Games by an American satellite had convinced the Indian government of the potential of using satellites to address the problems affecting the country. ISRO's first chairman, Sarabhai, explained India's role in the Cold War-dominated global space race of the 1960s:

> There are some, who question the relevance of space activities in a developing nation. To us there is no ambiguity of purpose. We do not have the fantasy of competing with the economically advanced nations in the exploration of the moon or the planets or manned space flight. But we are convinced that if we are to play a meaningful role nationally, and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society.[1]

Following up on the Olympics example, ISRO wanted to test if television could help in national development. Its first endeavor was the satellite instructional television experiment (SITE), which broadcast programs on health and farming practices to 200,000 people across 2,400 villages using an American satellite. SITE also trained 50,000 science teachers in primary schools. Kumar explained the program's significance, "SITE, the equivalent of today's direct-to-home technology, reached some of the most under-developed parts of India at a time when television was available only in four cities and people had to wait for hours in the telegraph office to make a phone call."

In parallel, ISRO worked on the capacity to build satellites and launch vehicles. Progress was slow as India received little technological assistance from abroad. As launch vehicle technology could also be used for military purposes, other countries were unwilling to share. In 1974, ISRO's access to technology was further impacted by sanctions following India's first nuclear bomb test. Consequently, ISRO's first satellite was launched by the Soviet Union. It was only in 1980 that ISRO successfully launched a satellite through its own launch vehicle. ISRO built on this success by experimenting and devising home grown solutions. Nageswara Rao, deputy director of ISRO Satellite Center reflected on ISRO's early days, "It was difficult to get space qualified components and systems due to technology control regimes, but we came up with unique and indigenous solutions to tide over these problems."

By 2016, ISRO had acquired greater competence and developed an infrastructure for space research. It had two types of launch vehicles, the polar satellite launch vehicle (PSLV) and the geosynchronous satellite launch vehicle (GSLV). (See **Exhibit 2** for details on ISRO's vehicles.) The PSLV was designed primarily for launching the lighter earth observation satellites at lower altitudes and the GSLV for launching the heavier communication satellites at higher altitudes. Further, ISRO, in its quest to reduce the cost of access to space, had successfully launched the reusable launch vehicle technology demonstrator and done a flight test of an air breathing propulsion engine.[a] ISRO launched its rockets from two launch pads at the Satish Dhawan Space Centre. (See **Exhibit 3** for details on ISRO's launch pads.) From launching only one rocket in two to three years in the early 1990s, ISRO had graduated to launching nine rockets in 2016. While most launches only carried satellites for national requirements, every year ISRO did at least one commercial launch and two-to-three mixed launches that carried satellites for both national and commercial use.[b] However, ISRO occasionally was forced to outsource launches to partners. For instance, the GSLV could not launch heavier communication satellites weighing between 3,500 kg and 4,500 kg. Therefore, ISRO used French launch provider Arianespace's Ariane 5 rocket for launching these satellites. While the Ariane 5 could power 6,500 kg into space, it was expensive; hiring the entire vehicle for a launch, cost $95 million.[c,2] Hence, ISRO was developing the GSLV-Mk III, a heavy launch capability launcher. It was anticipated that once GSLV-Mk III was ready, it would compete against SpaceX's Falcon 9 rocket.[3,d] ISRO was also planning to build a third launch pad at an estimated cost of $2 billion to meet the growing demand for launching satellites.[e,4]

An important consideration was working collaboratively with private players. ISRO benefited by being able to source more components and subsystems for its launch vehicles and satellites from outside firms thus saving on manufacturing cost and time. In turn, the partnership with ISRO helped private firms enhance their technological capability and reliability in engineering processes. By 2016, ISRO had outsourced manufacturing of roughly 80% of the PSLV's components to a network of 500 firms in India and retained responsibility only for system engineering, mission management, manufacturing certain critical components requiring extreme precision and reliability and the final assembly, integration and testing. ISRO's goal was to completely privatize the development of the PSLV launch vehicle by 2020. Arunan commented on the scope of ISRO's operations, "ISRO's model is different from NASA. While initially NASA used to do all space related activities, now it focuses on research having outsourced most of the commercial production to industry."

Organization Structure and Culture

ISRO was part of the government's space department that was directly under the Prime Minister. Its chairman was the secretary of the department of space as well as chairman of the space commission. ISRO operated through a countrywide network of centers and units spread across numerous Indian states, a model similar to the European Space Agency (ESA), which had 22 European countries as its stakeholders. (See **Exhibit 4** for ISRO's network.) As of 2016, ISRO had 16,902 employees.[f]

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[a] Launch vehicles designed for one time use were expensive and designing a reusable launch vehicle substantially reduced the cost of satellite launch. Cost could be further reduced if launch vehicles burnt fuel using atmospheric oxygen instead of an on-board oxidizer.

[b] A launch vehicle could accommodate 1 main satellite and 10 smaller satellites. The actual number of satellites depended on the launch vehicle's tonnage capacity and the weight of each individual satellite.

[c] The Ariane 5 rocket could lift 6,500 kg into GTO.

[d] Each Falcon 9 launch cost about $62 million. SpaceX had a lower cost structure than traditional players. It had a lean team and produced everything in-house. It also tried to increase the use of common components to achieve economies of scale. For instance, it had only one type of engine as opposed to the PSLV that had multiple types of engines and auxiliary engines.

[e] An exchange rate of 1USD=INR 67 was used for all conversions.

[f] 12,300 were scientists and technical experts and the remaining were engaged in administrative activities.

ISRO recruited graduates from engineering colleges. It hired an insignificant fraction of students from the Indian Institutes of Technology (IITs), India's premier technology institutes.[g] Recruiting students from the elite institutions was difficult, as many students believed they could find work that was more lucrative in the private sector or by pursuing a MBA or pursuing higher studies in foreign countries. The largest pool of new hires came through an open recruitment process across 100+ universities. ISRO's hiring strategy had been to find the technically best and most motivated candidates from the second and third tier colleges. V. Adimurthy, senior advisor of interplanetary missions at Vikram Sarabhai Space Centre, explained ISRO's hiring philosophy, "We look for strength in fundamentals, wherever the person is from. More than the pedigree of the institution, what matters is the individual."[5] In 2007, the Department of Space set up the Indian Institute of Space Science and Technology (IIST) to meet ISRO's demand for highly skilled people. About one-quarter of ISRO's yearly 400 hires came from IIST. Students were accepted to IIST only if they passed the entrance exams to the IITs. To better support the institute and future space engineers, the Indian government also provided financial assistance to students who secured a minimum GPA of 7.5 (on a scale of 10). This covered tuition fees, room and board, a book allowance and medical expenses. Many IIST students completed their internships at ISRO.

Regardless of point-of-recruitment, ISRO extensively trained all new engineers. All new hires underwent a 3- to 4-month classroom-training program covering diverse fields. Rao explained:

> We want to expose them to various aspects of our work. We want them to understand our processes of building rockets, satellites and other payloads, launching and monitoring satellites, and developing space based applications for various purposes.
>
> We are trying to ensure that the new people have a wide breadth of knowledge. For instance, during satellite design, people from multiple departments are present in the clean room so that they can learn from each other and understand how things fit together.

In parallel, ISRO tried to build a collaborative and transparent culture. New employees worked closely with more experienced seniors. This helped the younger employees understand the nuances and systemic aspects of the complex space technology and imbibe the unique 'ISRO culture'. People across divisions collaborated with each other. Further, employees were encouraged to share their views and ideas. ISRO shared details of its missions with all its employees and sought feedback from them.

To support individual initiative and innovation, ISRO offered modest grants for employees to pursue their own research. Additionally, facilities and laboratories were made available for these projects. Rakesh explained the benefit, "This excites them and they learn quickly on the job. Sometimes the things they develop get into a launch vehicle and this gives them unparalleled satisfaction." Rao recollected how access to ISRO's facilities had been a big motivator for him during his early days: "I am the son of farmers and the first person from my village to pursue an undergraduate course. Joining ISRO and then being allowed to enter the clean room, the place where things were built and only a few people were allowed entry, was a big honor."

Job satisfaction and commitment to work in technically challenging missions superseded the modest salaries at ISRO. Salaries were comparable to other government employees and private sector firms but much lower than those earned by management graduates and engineers in the IT sector in

[g] In 2014, only 2% of ISRO's employees were graduates from premium Indian engineering institutes such as the IITs and National Institutes of Technology.

India.[h] Scientists at ISRO earned about one-fifth of their counterparts in ESA and NASA.[6] This difference was largely due to the government's policy on pay and allowances for its employees. In FY2016, ISRO's budget was $1 billion (0.06% of India's GDP) compared to NASA's budget of $19.3 billion (0.11% of U.S.'s GDP).[7] (See **Exhibit 5** for ISRO's budget.) Although ISRO had lower compensation, it had a candid performance review process wherein people were promoted based on merit. This meritocratic culture had increased employees' dedication to their jobs.

ISRO's Societal Missions

ISRO had established four key programs to serve the country's developmental needs, domestic satellite communication, earth observation, disaster management support (DMS), and satellite navigation. ISRO instituted separate committees for each program to not only manage and coordinate the programs, but to also ensure that they were aligned with the needs of the end users.

The Indian national satellite system (INSAT), a large constellation of about 15 operational satellites in the geo-stationary orbit, provided regular services for telecommunication, television broadcasting, DTH, satellite newsgathering, Internet and meteorological services. Recently, INSAT had been extended to newer areas such as tele-education, tele-medicine and e-governance.

The earth observation program provided information related to land, ocean, atmosphere, and environmental shifts. A cluster of Indian remote sensing (IRS) satellites orbiting the earth at altitudes between 500 km and 720 km supported the program. Food and water security were two major focus areas of the program. Satellite imagery was used to predict crop yield, track the location of fish and monitor water table levels. This information was used to increase farm yields, save fishing fleets time and fuel, and increase the success rate of bore well drilling. Additionally, satellites helped mapping for urban and rural planning. Satellite imagery and data were also used to track mineral resources, observe oceans, identify weather patterns and study the impact of climate change.

The DMS program provided information required for efficient management of natural disasters. The program relied on Earth observation satellites (geostationary satellites), aerial survey systems and ground infrastructure to collect data. These data were used to predict and mitigate the damage caused by cyclones, India's most frequent and prevalent natural disaster. In 1999, satellite data only allowed the meteorological department to predict a deadly cyclone two days before landfall. The result was over 10,000 deaths. By 2013, ISRO enhanced its DMS infrastructure to accurately predict the precise path of a similar sized cyclone four days before landfall. Consequently, the government evacuated 1.2 million people and managed to contain the loss of life to just 44.[8] Further, during subsequent cyclones, the DMS system's early warning coupled with a coordinated ground based operation helped minimize the loss of life.

As ISRO's ability to map data and information for societal applications grew, the government's willingness to use the data also increased. According to Kumar, "Earlier it was difficult to convince the departments of the benefits of using space data. It took us three decades to convince the agricultural department to use our data on crop yield forecasts. Today things are different." In 2014, five government agencies, agriculture, fisheries, communication, disaster management and meteorology, were using most of the data. Subsequently, the government mandated that federal agencies and states implement space data in their operations. To identify synergies ISRO invited all ministries to a national

[h] A fresh engineer at ISRO had a fixed annual salary of about $10,000. In addition, he could earn performance incentives up to $1,100. He also had an unlimited health insurance cover for his family. Average starting salary for software engineers was about $5,000 and $27,000 for management graduates in India outside ISRO.

conference and educated them about the possible uses of space data. Consequently, by 2016, ISRO was running 200 projects across 60 government entities including the federal state governments and this demand was expected to grow even further.

ISRO's Science Missions

While an 'application-driven approach' as envisioned by Sarabhai was still the driving force for ISRO, ISRO also recognized that India should be 'second to none' in low-cost access to space and scientific exploration of outer space. Moreover, scientific missions had many societal and commercial spillovers. For instance, the lithium-ion battery technology developed by ISRO could be used by the automotive industry.

Chandrayaan

In October 2008, ISRO's PSLV launched its first mission to the moon, *Chandrayaan*-1. The spacecraft's mission was to complete chemical, mineralogical and photo-geologic mapping of the moon's surface. Scientifically, the launch was a success and India became the fifth country to send a spacecraft around the moon's orbit.[i] Furthermore, with the help of NASA's Moon Mineralogy Mapper, *Chandrayaan-1* found evidence of frozen water on the moon. Financially, the mission was also a success. *Chandrayaan-1* cost India $45 million, while Europe's Smart (2003) cost $85 million, Chinese Chang'e (2007) cost $187 million and the Japanese Kaguya (2007) cost $528 million.[9,j]

Mangalyaan

Having orbited the moon, in August 2012 ISRO set its sight on sending a satellite to Mars. Mylswamy Annadurai, director ISAC, reflected, "This was a challenging project. About 50% of the previous missions had been failures and unable to reach Mars in the first attempt." The mission aimed to demonstrate India's capability to conduct an interplanetary mission, including navigation and long-distance communication. It also planned to study Mars' surface features, minerals and atmosphere, and search for methane in the Martian atmosphere. The presence of methane[k] would strengthen a view that life once existed on Mars. Furthermore, understanding the rate of water vapor loss would help ISRO understand the planet's evolution so that it could predict similar changes on Earth. Rakesh explained, "This was our maiden interplanetary mission. It demonstrated that we had mastered the complicated technology of sending a satellite beyond the influence of the earth's gravity. Not even the Russians or Americans were successful in their first attempt."

Once India decided to go to Mars, ISRO had only a few months to execute the mission. The nearest launch window was in October 2013, and if ISRO missed it, the next opportunity was only in 2016.[l,10] The tight deadline required ISRO to implement systems that had been used in their low earth orbit missions. Arunan explained the strategy, "We didn't have ample money or time to develop new systems. So we adopted a modular plug-and-play approach of using heritage systems that had been

[i] U.S.S.R. sent its first successful lunar orbiter in March 1966, U.S. in August 1966, Japan in 1990, ESA in 2003 and China in 2007. The U.S.S.R. mission cost about $190 million and the U.S. mission about $160 million.

[j] An exchange rate of 1EUR=1.11 USD and 1YEN = 0.0096 USD was used for all conversions.

[k] Methane was a biomarker that indicated potential but not definitive sign of life.

[l] Countries looked for a time when the planet was aligned to earth such that they would need to spend the minimum energy to go to the planet.

utilized in other spacecraft." For instance, ISRO needed to build an autonomous spacecraft that could operate without human intervention because of the time delay involved in communication. Instead of building a new control system, ISRO modified the control system it had used for other missions. It added new mission-specific software that used inputs to control the systems and self-correct trajectory in case of any anomaly.

ISRO also needed to stick to a tight budget. It was allocated $67 million for the mission, about one-tenth the funds NASA apportioned for its MAVEN mission that was launched around the same time. (See **Exhibit 6** for MOM's cost break-up.) ISRO decided to use the proven PSLV, cap the payload weight at 15 kg by miniaturizing the instruments, and use low cost reliable components and systems. Arunan gave an example, "NASA uses extremely reliable components that can withstand high radiation doses. We cannot afford these expensive components. We used cheaper components that can withstand lower dosages. We tested these components to see if they could sustain higher radiation and they survived, so we used them."

On November 5, 2013, ISRO's PSLV launched the Mars Orbiter Mission (MOM) or *Mangalyaan* (Sanskrit for "Mars-craft"). Since the PSLV did not have enough power to launch the spacecraft into Trans-Mars' orbit, ISRO used the concept of a slingshot. (See **Exhibit 7** for a diagram of the slingshot technique.) The PSLV first placed the spacecraft in an elliptical orbit with a perigee, or low point, of 248 km and apogee, or high point, of 23,553 km. In the next "orbit raising" phase, MOM's main liquid rocket engine was fired six times. This was done when the spacecraft was closest to earth and helped eventually raise the apogee of the orbit to 193,000 km. During this one-month period while MOM was still within Earth's communication range, ISRO tested all its systems. The systems were also calibrated. Finally, on December 1, 2013, MOM's engine was fired once more for a precise duration that propelled the spacecraft out of the earth's gravitational field and into a Mars Transfer Trajectory. Arunan deliberated on this maneuver, "We didn't go to Mars in the textbook fashion. Using PSLV for the mission called for the slingshot technique which was appreciated by other space agencies including NASA." Three hundred days later on September 24, 2014, MOM reached Mars orbit. The ISRO scientists fired MOM's main engine once more to retard its speed and it was successfully captured by Mars' gravity. The last step was a big achievement as ISRO used an engine that could only be fired once. Arunan elaborated, "Once the engine is fired and the propellants wet the engine components and the plumb lines, the engine cannot be used again. This problem had caused the failure of Russia's first mission. We knew this risk but were willing to accept it. We did a ground test to check if the engine would fire twice or not. The test was successful and so we decided to use the engine." With the success of the mission, ISRO became the fourth space agency to reach Mars after the United States, Europe and Russia.

Mangalyaan's success had scientific, technological and organizational benefits for ISRO. Scientifically, MOM captured high definition pictures of Mars and collected data on the concentrations of carbon dioxide, nitrogen, carbon monoxide and oxygen. Of particular interest to both NASA and ISRO scientists were the notable spikes of methane levels across the planet.

Following the mission, ISRO was invited to participate in the international space station and began joint development projects with NASA.

Perhaps most significantly, the success of the Mangalyaan mission had larger benefits for India as a country. The achievement of the scientific feat despite huge budget constraints renewed respect in Indian scientific institutions. The impact was impressive: Indian scientific institutions expanded facilities, more students and universities started engaging in scientific research, Indian scientists published 52 papers in international journals, and numerous patents were filed. ISRO fueled the trend by making much of its work public. It shared mission details live with people through Facebook, explained some of their key maneuvers in depth providing engineering details and calculations and even accepting some suggestions from the people. ISRO seemed to be following in NASA's footsteps, which actively used social media to share details of its missions. ISRO also encouraged Indian researchers to analyze MOM data by announcing contests for solving certain problems. Kumar explained their open source strategy: "We wanted to make the younger generation more aware about space and rocket science. We have a lot of unexplored data due to limited manpower and we want to outsource some of the analysis." ISRO's strategy was similar to NASA, which had historically invited the public to participate in its science and technology activities through competitions, crowd sourced challenges and citizen science projects.

Future Missions

ISRO had ambitious plans for future scientific missions, including two smaller missions and sequels to the *Chandrayaan-1* and *Mangalyaan* successes. In September 2015, ISRO had launched Astrosat, a dedicated astronomy mission aimed at studying celestial sources of X-ray, optical and UV spectral bands. ISRO enabled the development of the mission with the participation of major research institutions and universities. The mission was scheduled to last five years. Additionally, India planned to launch a solar observatory in 2019-2020. The PSLV mission would place a satellite in a halo orbit[m] around the Lagrangian Point 1 (L1), about 1.5 million km from the earth so that it could continuously observe the sun and the solar corona.[n]

Chandrayaan-2, an ambitious mission to land a rover on the moon, was scheduled for early 2018. Only the United States, Russia and China had previously succeeded in such an undertaking. It was difficult to land softly on the moon's hard surface since there was no atmosphere to slow down descent. It was equally difficult to design a rover that could navigate the moon's uneven terrain and withstand extreme temperature variations. The scientific payloads onboard the rover would conduct mineralogical and elemental studies of the lunar surface, while a lunar orbiter would conduct surface mappings. The approximate budget for the mission was about $90 million, with comparable missions from the United States and Russia having cost roughly 8 to 10 times as much. ISRO was also keen to conduct a follow-up to the Mars mission sometime around 2020–2021. The scientific mission planned to use its GSLV Mark 2 to launch a satellite with a payload capacity of 100kg. To achieve this increased capacity, ISRO would use the aero braking[o] technique to land on the moon. The technique would save about 150 kg of fuel that could be allocated to increase the payload weight. Additionally, ISRO wanted to further investigate Venus and asteroids, as many scientists believed that asteroids could be mined for energy resources. Jason Crusan, director of the advanced exploration systems division at NASA commented on ISRO's capabilities, "If India wanted to, it could be the next nation to put a human in space; it has all the technologies to do it today."

ISRO's Commercial Operations

In September 1992, ISRO set up Antrix Corporation, a wholly owned subsidiary of the Indian government, as ISRO's marketing arm. Rakesh reflected on Antrix's establishment, "ISRO is basically

[m] A halo orbit was a circular or elliptical orbit wherein a spacecraft would remain near a Lagrangian point owing to the interaction between the gravitational pulls of the earth and the sun.

[n] The outer layers of the sun extending to thousands of km above the disc were called the corona. The corona had a temperature of more than a million degrees Kelvin, much higher than the solar disc temperature of around 6000K.

[o] Aero braking was a technique of slowing down a spacecraft by using the friction of a planet's atmosphere.

a research and development organization and we needed a separate agency to take care of the commercial aspects of the space business."

Antrix grew rapidly from these humble beginnings. In 2008, it was declared as a *Miniratna*[p] by the Indian government and given financial autonomy to make investments up to a certain limit without explicit government approvals. This autonomy provided further impetus to Antrix and by FY2015, it was earning $278 million of revenue from leasing communication satellite transponders, providing launch services, selling satellite data and other services. (See **Exhibit 8** for Antrix's key financial indicators.) About 75% of Antrix's operating revenue came from leasing communication satellite transponders to firms providing services such as DTH, VSATs, digital newsgathering and mobile backhaul. DTH was a very large segment in India owing to the profusion of regional language channels.[q] Antrix also leveraged ISRO's spare launch capacity by providing commercial launch services. It had launched 79 international customer satellites from 21 countries onboard PSLV till December 2016.

By 2016, Antrix had cornered a 0.6% share of the $5.5 billion global launch services market.[11] Although about 80% of the market was focused on launching heavy satellites weighing between 2–6 tons, there was a growing demand for launching smaller satellites and CubeSats, satellites weighing between one and 20kg.[r,12] (See **Exhibit 9** for a picture of a CubeSat.) In 2015, 49% of the total satellites launched worldwide were CubeSats.[13] Crusan commented on the CubeSat revolution:

> Firms are developing CubeSats in large numbers, and deploying and replenishing their constellations more frequently. Even high school students are building CubeSats. In a few years, the number of CubeSats will exceed the number of other satellites thus increasing the demand for commercial launch services. The ride share approach where CubeSats are part of a large government or commercial launch may not support this demand. Smaller launch vehicles can help meet the requirement of commercial CubeSat operators who need to launch satellites in a very specific orbit.

While United Launch Alliance (US), International Launch Services (Russia) and Arianespace (France) were the three leading players in the satellite launch service market; newer companies such as U.S.'s Orbital Science Corporation and SpaceX were rapidly gaining market share. China and Japan had also recently entered the commercial space launch market. Moreover, newer firms that offered smaller launch vehicles to cater to the growing CubeSat market were emerging. (See **Exhibit 10** for details on select small launch vehicles.) There was also a rise of comprehensive launch service and mission management providers such as Spaceflight. These firms typically bought an entire launch, acquired customers for the launch and provided integration services such as satellite sequence deployment. India's expertise lay in providing a cost effective and reliable vehicle for launching light satellites, less than 1,500 kg. Rakesh explained, "PSLV is one of the most accurate in terms of delivering a satellite to the exact slot specified by a customer. This helps save fuel and extend the satellite's life."

[p] State owned enterprises which met certain financial and profitability criteria were called *miniratnas* or small jewels and granter certain autonomy.

[q] India had 22 official languages.

[r] CubeSats, small inexpensive satellites weighing between 1.33 kg and 20kg, were initially used for academic and government purposes, but were increasingly being used for many commercial applications such as earth observation and telecommunication. CubeSat cost varied between tens of thousands of dollars and a few million dollars.

PSLV's inherent advantages were creating many commercial opportunities for Antrix. One was to become a global player in the transponder renting business. Success in this market would depend on an ability to provide continuity of service. Rakesh explained, "We should have enough launch capacity to ensure that before a satellite's life ends, we can launch a replacement satellite. Today, however we have a constraint on the number of launch vehicles we can build as well as the number of launches that we can do from our two launch pads." ISRO's two existing launch pads could support only 11 launches a year and with certain modifications 24 launches. Moreover, it would cost about $2 billion to build a new launch pad.

Another opportunity was to cash in on the booming small satellite sector where there was a shortage of launch capacity globally. Firms such as U.S. based One-web were planning to provide broadband services through a global constellation of hundreds of small satellites positioned at an altitude of about 500 km above the earth. Rakesh commented on this opportunity:

> Many firms are approaching us for launching small satellites and we are ideally positioned to take advantage of this opportunity. We do not see low cost players such as SpaceX as our competitors because their vehicle is very big and eight times as powerful as the PSLV. For SpaceX, small satellites will be piggyback rides, whereas PSLV can offer exclusive launches that position the satellites in exact locations.

Decision

Kumar was aware that his meetings with users, both national and international, reflected the enormous but conflicting demand for ISRO's services and resources. To satisfy the communication and data needs of the government, ISRO needed to launch at least 12 satellites each year. It also needed to prepare for some critical science missions such as *Chandrayaan-2* and perhaps a second mission to Mars. Finally, there was a large commercial opportunity before Antrix. Since ISRO could only launch 11 vehicle missions a year and at best increase this to 24 by 2017, Kumar realized that it was critical to define future priorities. It was also imperative to think through the implications of strategy choices. What kind of human capital needed to be developed? What processes needed to be strengthened? What external collaborations with Indian space players needed to be fostered?

Exhibit 1 ISRO Timeline

Date	Event
February 1962	Indian National Committee for Space Research (INCOSPAR) established.
November 1963	First sounding rocket launched from Thumba Equatorial Rocket Launching Station.
January 1965	Space Science and Technology Center established in Thumba.
January 1967	Satellite Telecommunication Earth Station set up in Ahmedabad.
August 1969	ISRO formed.
April 1975	Aryabhatta, the first Indian satellite, launched using a Russian rocket.
1975-1976	ISRO along with NASA conducted Satellite Instructional Television Experiment (SITE), a one-year program that used satellite TV broadcasting to educate people in rural India.
1977-79	Satellite Telecommunication Experiments Project (STEP) conducted. It used satellite technology to enhance domestic communication.
July 1980	India's first indigenously created launch vehicle SLV-3 launched the Rohini satellite in orbit.
April 1982	Indian National Satellite System (INSAT) commissioned to work on broadcasting, telecommunication, meteorology and rescue operations.
April 1984	The first Indo-Soviet manned space mission launched.
1987-1994	The Augmented Satellite Launch Vehicle (ASLV) program, supporting a larger payload than the SLV-3, conducted. It had four developmental flights of which the third one in 1992, succeeded in placing a satellite in orbit.
March 1988	India's first remote sensing satellite, IRS-1A launched.
May 1994	The Polar Satellite Launch Vehicle (PSLV) placed its first experimental satellite in orbit. The PSLV was designed mainly to launch satellites into lower orbits up to 600 km altitude.
April 2001	Successful flight test of Geosynchronous Satellite Launch Vehicle (GSLV) designed mainly to deliver communication satellites to the highly elliptical 36,000 km orbits.
October 2008	India's first lunar mission launched.
2014	Mangalyaan, India's first interplanetary mission launched.
December 2014	The first experimental suborbital flight (LVM3-X/CARE) of India's next generation launch vehicle LVM3 (GSLV Mk-III) was successfully conducted. The crew atmospheric module carried on-board to a height of 126 km was successfully recovered later.
September 2015	Astrosat, India's first dedicated astronomy satellite launched in an orbit 650 km above the earth.
September 2016	First operational flight of GSLV Mark II using an indigenous cryogenic engine. (In the early 1980s, ISRO decided to develop a cryogenic engine that would be more powerful than its current engines. Since it was technologically challenging to indigenously develop such an engine, ISRO decided to import it from Russia, the only country willing to share the technology with India. In 1993, US imposed sanctions on Russia and India stalling the technology-transfer deal and forcing ISRO to develop its own technology.)

Source: Company documents.

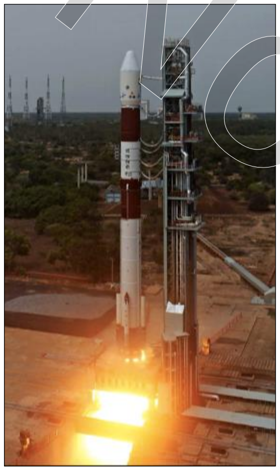
Exhibit 2 ISRO's Launch Vehicles

Launch Vehicles	Capability	Payload
PSLV 	1,750kg to low earth orbit (LEO) and 1,425 kg to geosynchronous transfer orbit (GTO).	Remote sensing, navigation, communication and meteorological satellites
GSLV 	5,000 kg to LEO and 2,500 kg to GTO.	Communication satellites
GSLV Mark III 	8,000 kg to LEO and 4,000 kg to GTO.	Communication satellites

Source: Adapted by casewriters from company documents, http://164.100.47.192/Loksabha/Questions/QResult15.aspx?qref=10792&lsno=16, http://164.100.47.192/Loksabha/Questions/QResult15.aspx?qref=22994&lsno=16.

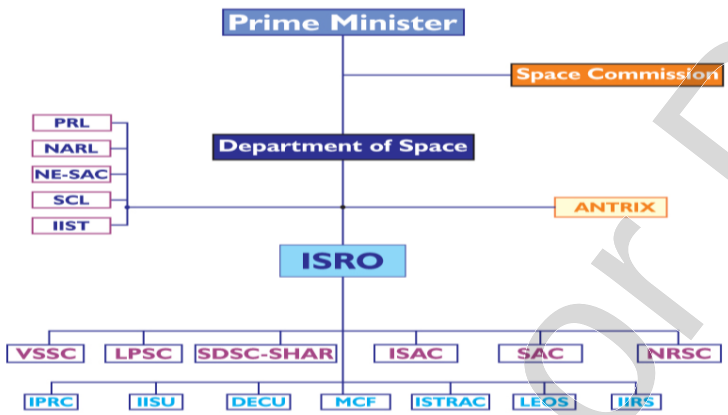
Notes: A LEO was an orbit around the earth with an altitude between 160 km and 2,000 km. A GTO was an elliptical orbit with an apogee (high point) of about 37,000 km. A satellite was placed into a GTO before being transferred to a geosynchronous or geostationary orbit. A geosynchronous orbit was a low inclination orbit around the earth. A satellite placed in a geosynchronous orbit had an orbital period equal to the earth's rotation period and hence returned to the same point in the sky at the same time each day. A geostationary orbit was a type of geosynchronous orbit that was circular and above the earth's equator. A satellite placed in such an orbit appeared to hang motionless at a fixed position in the sky to ground observers. Communication and weather satellites were often placed in geostationary orbits.

Exhibit 3 ISRO's Launch Pads

	Launch Pad	Description	Capacity
FIRST LAUNCH PAD		Designed as per the integrate on pad concept. The individual stages of the launch vehicle were integrated on the launch pad itself. The Mobile Service Tower (MST), equipped with foldable and vertically repositionable access platforms facilitated the integration of the launch vehicle. Next, the fueled spacecraft arrived at the launch pad and got integrated with the launch vehicle. A few hours before the launch, the MST was moved away from the launch pad on a rail track. Originally built for PSLV, later adapted to launch GSLV.	Six launches a year. Integration at the launch pad took 35 days and refurbishing the pad after each launch took 20 days. ISRO planned to increase the capacity to 12 launches a year by constructing a booster integration complex where the first stage of the PSLV could be built in parallel. Once the refurbishment was over the first stage could be taken by rail to the launch pad thus saving time.
SECOND LAUNCH PAD		Designed as per the integrate, transfer and launch concept. The entire vehicle was assembled and checked-out on a mobile launch pedestal in the Vehicle Assembly Building (VAB) and then moved in vertical position to the launch pad on a rail track. There also was a solid stage assembly bay (SSAB) for assembling the first stage of GSLV Mark III. The second launch pad could be used for PSLV, GSLV and GSLV Mark III.	Nine launches a year. It took time to reconfigure the pad after each launch to a new vehicle type. Since there was only 1 VAB, the capacity was limited to 5 launches a year (It took 20 days to make the VAB compatible with another type of vehicle and 8 days of activities had to be carried out at the launch pad before launch.) ISRO planned to increase the capacity to 12 by 2017 by adapting the SSAB to build the first stages of both PSLV and GSLV and building a second vehicle assembly building connected to the launch pad by rail.

Source: Adapted by casewriters based on company documents.

Exhibit 4 ISRO's Organization Structure



Acronym	Site	Location	Function
PRL	Physical Research Laboratory	Ahmedabad, Gujarat	Basic research on numerous fields such as astronomy, planetary science and exploration, space and atmospheric sciences, theoretical physics.
NARL	National Atmospheric Research Laboratory	Tirupati, Andhra Pradesh	Atmospheric research.
NE-SAC	North Eastern Space Applications Center	Shillong, Meghalaya	Developmental support to the northeastern region.
SCL	Semi-Conductor Laboratory	Chandigarh	Design, development, fabrication, assembly and testing of microelectronics.
IIST	Indian Institute of Space Science and Technology	Thiruvananthapuram, Kerala	Space university providing education in space science and technology.
VSSC	Vikram Sarabhai Space Center	Thiruvananthapuram, Kerala	Design and development of launch vehicle technology.
LPSC	Liquid Propulsion Systems Center	Thiruvananthapuram, Kerala	Development of propulsion systems for launch vehicles and satellites.
SDSC	Satish Dhawan Space Center	Sriharikota, Andhra Pradesh	Launch base infrastructure.
ISAC	ISRO Satellite Center	Bengaluru, Karnataka	Design, development, fabrication, and testing of satellites.
SAC	Space Applications Center	Ahmedabad, Gujarat	Development of sensors and payloads.
NRSC	National Remote Sensing Center	Hyderabad, Andhra Pradesh	Reception and processing facilities for remote-sensing data.
IPRC	ISRO Propulsion Complex	Mahendragiri, Tamil Nadu	Creation of propulsion technology products.
IISU	ISRO Inertial Systems Unit	Thiruvananthapuram, Kerala	Design and development of inertial systems for launch vehicles and spacecraft programs.
DECU	Development and Educational Communication Unit	Ahmedabad, Gujarat	Conduction of socio-economic research and evaluation of space-based societal applications.
MCF	Master Control Facilities	Hassan, Karnataka and Bhopal, Madhya Pradesh	Monitoring and control of geostationary and geosynchronous satellites.
ISTRAC	ISRO Telemetry, Tracking and Command Network	Bengaluru, Karnataka	Tracking support for ISRO's satellite and launch vehicle missions.
LEOS	Laboratory for Electro-optic Systems	Bengaluru, Karnataka	Design, development and production of electro-optic sensors and camera optics.
IIRS	Indian Institute of Remote Sensing	Dehradun, Uttarakhand	Education and training programs on remote sensing geo-informatics.
Antrix	Antrix Corporation	Bengaluru, Karnataka	ISRO's commercial arm.

Source: Company documents.

Exhibit 5 ISRO Budget Allocation ($ million)

	2015–2016	2016–2017 (budget estimate)
Space technology	649.52	781.44
Space applications	144.42	154.39
INSAT operational	174.29	118.82
Space sciences	44.44	43.13
Direction and administration and other programs	26.05	22.99
Total	1,038.72	1,120.77

Source: Company documents.

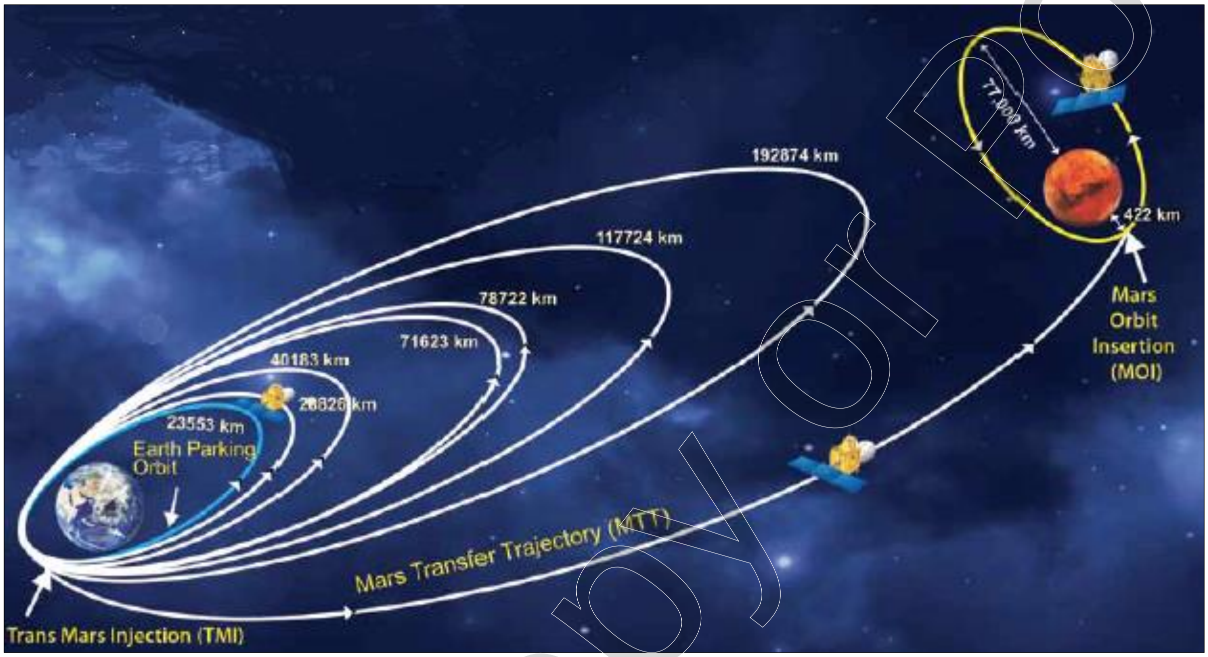
Exhibit 6 MoM Cost Structure

System Description	Approved Cost ($ million)
Space segment	32.09
Ground segment	10.45
Project management/ contingency	6.72
Program elements	1.49
Launch cost (PSLV-XL)	16.42
Total	67.16

Source: Quora, "What is the breakdown cost for ISRO's Mars Orbiter Mission (Mangalyaan)?" https://www.quora.com/What-is-the-breakdown-cost-for-ISROs-Mars-Orbiter-Mission-Mangalyaan, accessed May 2017.

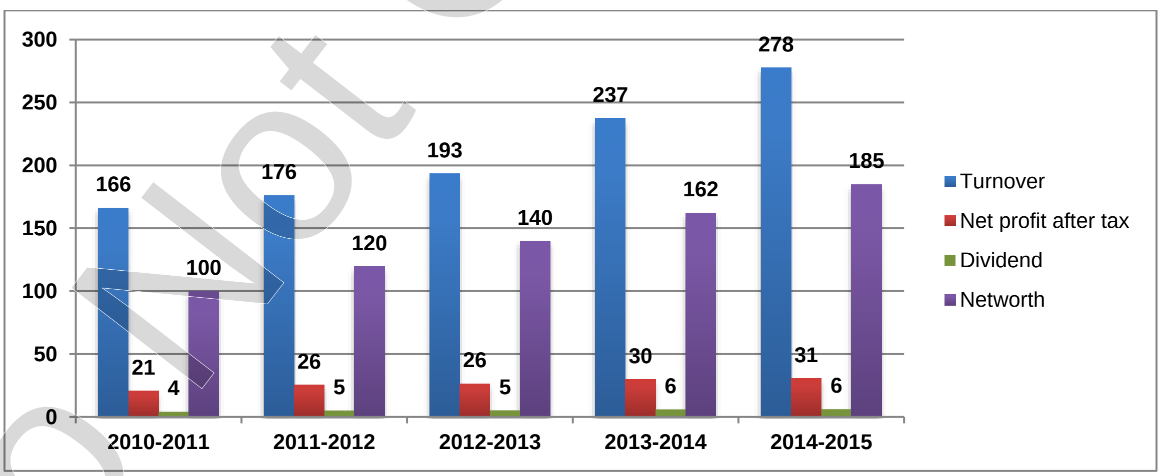
Notes: As of March 31, 2014, $47.76 million was spent on MOM. Of this $14.22 million was spent on the launch vehicle, $2.34 million on equipment.

Exhibit 7 Diagram of the Slingshot Technique



Source: Company documents.

Exhibit 8 Key Financial Indicators for Antrix Corporation over Time ($ million)



Source: Antrix Corporation Ltd., Annual Report 2014-2015, (Bengaluru: Antrix Corporation, 2015), p. 7, http://www.antrix.gov.in/sites/default/files/article-attachments/ANNUAL%20REPORT%202014%20-2015%28ENGLISH%29.pdf, accessed November 2016.

Exhibit 9 Picture of a CubeSat

Source: NASA, https://www.nasa.gov/directorates/somd/home/CubeSats_initiative.html.

Exhibit 10 Details of Select Very Small Launch Vehicles

Launch Vehicle	Alpha	Electron	LauncherOne	Lynx Mark III	SOAR
Company	**Firefly Space Systems**	**Rocket Lab**	**Virgin Galactic**	**XCOR Aerospace**	**Swiss Space Systems**
LEO capacity (kg)	400	150	400	10	250
First flight	2017	2016	2017	2018	2017
Price ($ million)	8.0	4.9	10.0	0.545	10.5
Price ($) / kg	20,000	32,667	25,000	54,500	42,000

Source: Satellite Industry Association, *State of the Satellite Industry Report*, June 2016, http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf, accessed December 2016.

Endnotes

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[2] Vasudevan Mukunth, "Four Reasons You Should Pay Attention to ISRO's Successful GSLV F05 Launch," The Wire, September 8, 2016, http://thewire.in/64280/gslv-mk2-cryogenic-insat-3dr/, accessed November 2016.

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[5] Payal Gwalani and Adarsh Jain, "Just 2% of ISRO's Engineers are from IITs, NITs," *The Times of India on the Web*, September 26, 2014, http://timesofindia.indiatimes.com/home/education/news/Just-2-of-Isros-engineers-are-from-IITs-NITs/articleshow/43458127.cms, accessed July 2016.

[6] Jacob Koshy, "India Aims to Boldly Enter The Outsourced Space Race," *Newsweek*, 10, October 2014, http://www.newsweek.com/2014/10/10/india-aims-boldly-enter-outsourced-space-race-274500.html, accessed July 2016.

[7] Tariq Malik, "NASA's $19 Billion 2017 Budget Request: A Summary," Space.com, February 9, 2016, http://www.space.com/31875-nasa-2017-budget-request-summary.html, accessed January 2017.

[8] UNEP Global Environmental Alert Service, *Environmental Governance, Disasters and Conflicts*, November 2013, http://www.unep.org/pdf/UNEP_GEAS_NOV_2013.pdf, accessed November 2016.

[9] A. V. Raghunathan, "Chandrayaan-1 mission completed in cost-effective manner, says top official", *The Hindu on the Web*, February 28, 2011, http://www.thehindu.com/todays-paper/tp-national/chandrayaan1-mission-completed-in-costeffective-manner-says-top-official/article1496512.ece, accessed November 2016.

[10] The spacecraft leaves Earth in a direction tangential to Earth's orbit and encounters Mars tangentially to its orbit. The flight path is roughly one half of an ellipse around sun. Eventually it will intersect the orbit of Mars at the exact moment when Mars is there too. Such an arrangement occurs periodically at intervals of about 780 days.

[11] Press Information Bureau Government of India Department of Space, "India's Share in International Satellite Market," press release, July 21, 2016, http://pib.nic.in/newsite/PrintRelease.aspx?relid=147441, accessed November 2016.

[12] Jacob Koshy, "India Aims to Boldly Enter The Outsourced Space Race," *Newsweek*, 10, October 2014, http://www.newsweek.com/2014/10/10/india-aims-boldly-enter-outsourced-space-race-274500.html, accessed July 2016.

[13] Satellite Industry Association, *State of the Satellite Industry Report*, June 2016, http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf, accessed December 2016.