TENSION writ large on his forehead, body stooped on the console, ISRO chief K. Radhakrishnan was in a pensive mood. So were the 60-70 odd engineers in the control room, who were intensely staring at the consoles. Everyone spoke in whispers, hustled around, stiff and anxious. The time ticked by, and in the tensed silence one could have heard heartbeats.

At that instant, there was no radio link between the Mars Orbiter Mission (MOM) and the ground station as MOM was on the other side of Mars.

As the electronic clock on the wall silently flashed the time, one could feel an air of expectancy and anxiety. As soon as the clock struck 8.00 am, a broad grin appeared on ISRO chief Radhakrishnan’s countenance. Now relaxed, the chief swiftly reached for his phone. The broad smile and the abrupt change in the body language gave it away.

As I turned my gaze towards the large screen display on the wall, the figures that were frozen still for the last many minutes, suddenly sprang to life as fresh data flashed on. The accelerometer showed 1099 m/sec. I knew that was it.

ISRO had made it – MOM had entered into the orbit of Mars! The journey that started about 10 months ago on a balmy Tuesday evening had succeeded. A new chapter in Indian space history had commenced.

The country is ecstatic with joy and full of pride at the successful accomplishment of one of the toughest challenges that Indian space scientists have ever faced – launching a spacecraft towards Mars and injecting it into the orbit of the Red Planet.

Here’s a first-person account of the tension, trepidation, and excitement that filled ISRO’s Mission Control Complex at Bengaluru during the final tense moments before the Indian spacecraft was safely ensconced into the Mars orbit.

PSLV-C25 lifts off carrying the Mars Orbiter spacecraft (Courtesy: ISRO)
India had become the first Asian country (Chinese and Japanese missions had failed en route), the first country in the world to succeed in the very first attempt, and the fourth country/agency in the world to reach Mars (after NASA, Russian/USSR and European Space Agency).

**MOM Gets Ready**
India’s mission to Mars was conceived way back in 2010. After intense scrutiny, the final go-ahead was given by the Government on 3 August 2012. Within two days ISRO commenced the preparation of the Polar Satellite Launch Vehicle (PSLV) in Thiruvananthapuram and spacecraft fabrication at the ISRO satellite centre in Bangalore.

Working day and night, the launch vehicle, spacecraft and payloads were fabricated, tested, integrated and made ready, fit to fly in a record time of 15 months. All the components were moved to the Sriharikota-SHAR launch site for integration on 2 August 2013, well ahead of the scheduled initial launch date. MOM was mated with the launch vehicle, fuelling was commenced, and all was set for the launch on 28 October.

Alas, nature played spoil sport. Rough seas and bad weather delayed the scheduled arrival of two ships hired by ISRO for tracking the rocket launch from their location in the Pacific. Without these the launch would have been tricky. Rescheduling the launch became imperative.

Although they had no option but to delay, the ISRO was restive; if they failed to launch the rocket by November 19, then they would have to abort the mission and shelve it for two years. The launch window was fast approaching and the ships still had not taken their positions in the Pacific.

**Route to Mars**
The road to Mars is not a straight line. Indeed, H.G. Wells in his *War of the Worlds* speculated that when Mars and Earth were in inferior conjunction (same side of the Sun, therefore at the least distance from each other), a canon could be fired from Earth aimed at Mars enabling transportation. ‘Aim and Shoot’ could work well in science fiction, but in reality by the time the spacecraft nears the point where Mars was in space, it would have moved away in its orbit around the Sun.

Therefore, just like one shoots a flying bird by aiming ahead of its flight path rather than at its current location, it is imperative that the arrival of the spacecraft at the Mars orbit coincides with the arrival of Mars itself at the same location in space.

Further, flight paths of objects in interplanetary space are affected by the Sun’s gravity and are curved. Kepler’s laws show that all spacecrafts travel in an orbit or trajectory that is part of conic sections – ellipse, circle, parabola or hyperbola. If you force a straight line path, then one would have to spend enormous amounts of fuel to counteract the Sun’s gravity. Besides, if one launches the spacecraft in the same direction of the Earth’s orbit around the Sun, then one could get additional velocities relative to Sun, without expending fuel.

There are a number of curved orbits that one can contrive for a journey from Earth to Mars. Evaluating many such orbits, a German engineer Wolfgang Hohmann found an optimal orbit that had the least expenditure of energy. He published his results in a paper titled “The attainability of celestial bodies” in 1925, wherein he described the path, now named after him, Hohmann path, which required least amount of rocket burn or load of fuel as compared to all others. This path is an ellipse with perihelion P (point closest to the Sun) at the orbit of Earth and aphelion A (point most distant from the Sun) in the orbit of Mars.

In the Hohmann path, the spacecraft will travel in an elliptical orbit around the Sun, which will eventually intersect Mars. It is, therefore, imperative that both the spacecraft and Mars arrive at this point of intersection at the same time. If either one arrives earlier, the mission is lost. Timing the launch to allow a spacecraft and Mars to arrive at the same point and at the same time is important. Hence, you cannot shoot at Mars on any day of your choice.

To make a journey to Mars within a minimum energy budget, in this ideal orbit, the optimal time for launch is when Earth, Mars and Sun form an angle of approximately 44 degrees. Such an alignment occurs once in 780 days. The opportunity was there in October-November 2013 and thereafter only in January 2016. So if the launch window of October-November 2013 was missed then ISRO would have to keep waiting for two long years.

**Towards Mars**
Thankfully, the ships employed for their tracking facilities reached their scheduled places and the launch date was rescheduled to 5 November 2013. The PSLV rocket took the spacecraft to its initial 248 km x 23,500 km elliptical orbit. By performing several burns with its 440 N Liquid Apogee Motor (LAM) engine, when the spacecraft was closest to Earth (perigee), the altitude of the apogee (the
The farthest point of its orbit from Earth was raised in succession. Although one of these orbit-raising manoeuvres faced a glitch, it was set right in the subsequent supplementary operation.

The PSLV rocket imparted a velocity of 9.8 km/sec to MOM; the subsequent six orbit raising burns added a combined velocity of 0.873 km/sec second. Finally, on December 1 one more time the LAM was activated and this burn gave it a shove of 0.648 km/sec. All the impulses combined to give the spacecraft a velocity of 11.4 km/sec, slightly larger than the escape velocity of 11.2 km/sec.

Having attained the escape velocity on 1 December 2013, the spacecraft sped away from Earth and on 4 December navigated beyond 9.25 lakh million km for 300 days, even a slight deviation of arc second could take the spacecraft many kilometres away from Mars. For successful Mars orbit insertion, MOM had to arrive 500+ or –50 km from Mars at the crucial time of 7:17 a.m. on 24 September. Therefore, en route, the path of the spacecraft was monitored and three corrections were made to ensure the spacecraft arrived precisely at its destination for the rendezvous with Mars.

**Retro-firing**

Having gained impulse from the LAM burn as well as gravity assist, during its interplanetary travel the spacecraft was speeding at 22.1 km/sec with respect to the Sun. When the spacecraft nears the meeting point, if the spacecraft has to be captured by Mars, the speed of the spacecraft had to be reduced by about 1.1 km/s, failing which Mars Orbital Insertion would fizzle out. Although MOM had completed more than 99.9% of its journey on 24 September, about 680 million km in deep space, the manoeuvres scheduled in the morning were crucial and pivotal.

Since the crucial operation on 24 September involved providing negative thrust, LAM had to be retro-fired and rockets had to be used as a brake. If the negative thrust is more than anticipated, the resultant spacecraft velocity will be less and MOM will not enter into the projected orbit around Mars. The life of the spacecraft may be substantially reduced. If the negative thrust is less, the resultant velocity will be more making it impossible for gravitational capture by Mars – MOM would just flyby and be lost in space.

The LAM had to provide negative thrust; so it had to fire against the direction of motion of the spacecraft. Therefore, the spacecraft had to be rotated forward to align the LAM nozzles towards the velocity vector. After 300 days of inaction LAM had to be woken up and then made to fire flawlessly and provide the desired
negatives thrust. To add to the woes, the spacecraft would be at a distance of about 220 million km taking radio signals 12.5 min for a one-way journey. Unlike a remote car MOM could not be remote controlled in real-time.

To enable autonomous manoeuvres ISRO had uploaded time-stamped codes prior to the crucial day. The additional concern was that four minutes into the crucial retro-burn the spacecraft would go behind Mars. So, even time-lag data would not be available. It was a blind date.

**Control Room**

Even before the day (24 September) dawned and daylight broke, I reached Peenya, Bangalore, where ISRO’s Mission Control Complex (MOX) is situated, at around 3 am. The security check was stringent, as the PM was expected to visit the location.

MOX is the nerve-center of the MOM operations and is responsible for all spacecraft operations after launch, as well as for the health monitoring of the spacecraft and payloads. MOX is authorised for uplinking of commands for change of on-board configuration, payload operations and conduction of manoeuvres as required. Telecommands for changes of spacecraft configurations and payload operations are uplinked after verification and due authorisation from this center.

The centre is also equipped to handle special operations and contingency recovery. The MOX is linked through a secure network for data transfers with India’s 32-meter Deep Space Network antenna situated at Byalalu, about 40 km from Bengaluru as well as antennas at Canberra, Australia, Goldstone in California and Madrid.

Bus loads of ISRO engineers, men and women, smartly dressed were arriving at the scene. Many had a light jacket on with ‘ISRO’ embossed on it to brave the early morning chill. A strange mixture of excitement, apprehension, stress, and elation was writ large on their faces. This was a big day.

All of us entered the MOX and settled in our respective places. A light breakfast of idli and coffee was served. But for the next four hours or so no one even thought of taking a sip of water. All were engrossed in their tasks.

The MOX complex has two almost identical MOX centres. Each of these MOX control rooms was a sight in itself. Imposing and overwhelming. The size of a small auditorium with a seating capacity of about 60-70, it has rows of tables with consoles. The wall in front hosts six huge screens. While each console was devoted to monitoring a specific parameter, like the pressure in the fuel tank, the big screens placed high on the opposite wall provided a snapshot of vital information about the spacecraft health, like the temperature of the LAM.

**Date with Mars**

At around 4:19 the medium gain antennae came to life. Communication was established with the MOM. As the Byalalu ISRO’s deep space network antenna was not in the line of sight of the MOM at that time, the ground stations at Canberra and Goldstone provided the communication link.

As planned, at 6:56 the spacecraft began to somersault to point the nozzle of the 440 newton thruster towards the velocity vector. At 7:12 the MOM slipped into the night side of Mars arresting the velocity vector. At 7:17 the MOM went behind Mars, taking it away from the line of sight. All communications and telemetry ceased and the monitors froze. These were the moments of anxiety and tension. Almost all the engineers in the control centre stiffened. Although the figures in their console screens did not show any change, they kept gazing at them; as if by intensely staring one could make them work.

Exhilaration

On the dot, at 8:00 a.m. as the occultation ended, the spacecraft once again came in the line of sight of the Earth, and the telemetry resumed. The screens refreshed and new figures appeared. One could see Mylswamy Annadurai, Programme Director, Mars mission who had led the Chandrayaan project also, excitedly talking to his neighbour. Subbiah Arunan, Project Director of MOM, sprang up from his chair, a smile flashing all over his face.
and throwing up his hands in air like a cricketer who has just scored a century in his first outing. S.K. Shiva kumar, Director of ISRO Satellite Centre had a broad grin. Elated, V. Kesavaraju, Mission Director for post launch operations, got up to greet all his juniors.

The MOM had kept its date with Mars. The solemn and tense mood gave way to spontaneous joy and cries of delight. Many stood up and impulsively started to clap. Few were seen quietly wiping a tear of joy; some seemed numbed in disbelief, quietly allowing the moment to seep in. Senior and junior scientists could be seen greeting and cheering one another on the great accomplishment. Even the security personnel smiled and relaxed. Words are not enough to describe the celebratory mood that permeated the complex.

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ISRO had put in orbit MOM with a shoestring budget of about 450 crores, using the indigenously designed and developed LAM engine. The nation was joyous. It was indeed a great opportunity, to witness at close quarters, history being made.

Feather in the Cap

The burn was successful and the desired velocity of 1099 (instead of the planned 1098) m/sec was achieved. Telemetry confirmed that the 23-min burn had successfully reduced the spacecraft’s velocity from 5.7 km/sec to 4.6 km/sec with respect to Mars, placing the spacecraft in an orbit with the nearest point to Mars (periapsis) at 421.7 km and farthest point (apoapsis) at 76,993.6 km.

The inclination of orbit with respect to the equatorial plane of Mars is 150 degrees, and in this orbit the spacecraft takes 72 hours 51 minutes 51 seconds to go round Mars once. MOM has returned many pictures from the Mars Colour Camera which was one of the first payloads to be operated. ISRO has announced that it would test and operate the rest of the payloads one by one soon.

MOM was launched using ISRO’s low-power workhorse rocket, the Polar Satellite Launch Vehicle (PSLV), designed for putting satellites into low Earth orbit and used gravity assist manoeuvre to hurl the spacecraft towards Mars. Anticipating that the fuel lines and values could malfunction after 300 days of hibernation in deep-space, ISRO tweaked the engine and fitted it with a parallel set of lines that was opened only when the spacecraft was near Mars.

With PSLV it was possible to launch only a 1.3 tonne spacecraft. The bulk of the spacecraft load is fuel for orbit-raising manoeuvre and Mars orbit insertion. Hence, the actual payload, the scientific instruments, which could be accommodated, was just 15 kg. ISRO used miniaturized components and composite materials to pack the limited payload with five instruments that included a colour camera to obtain high resolution pictures, instrument to detect the presence of methane in the upper atmosphere and an instrument to measure the ratio of deuterium to hydrogen.

But ISRO’s maiden mission to Mars is essentially a technology demonstration mission; to demonstrate the capability of ISRO to innovatively launch a spacecraft towards Mars and then manoeuvre it into the Martian orbit.

Overcoming hurdles en-route, braving adverse space weather and radiation hazards, and maintaining reliable communication in deep space were the primary objectives of this mission. ISRO succeeded in this mission with aplomb putting India on a high pedestal among space-faring nations.

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