

AE 403 Spacecraft Attitude Control

Spring 2008 - Prof. Tim Bretl

Extra Credit Assignment

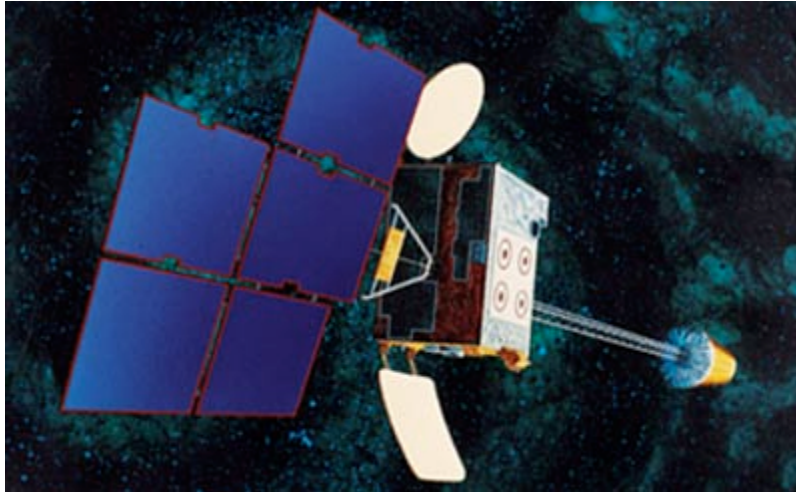
- Ashwin Jadhav

India's foray as a space power was initiated with the launch of the Aryabhata artificial satellite. The objectives of this project were to indigenously design and fabricate a space-worthy satellite system and evaluate its performance in orbit. The satellite carried three experiments, one each in X-Ray Astronomy, Solar Physics and Aeronomy. The satellite weighed 360 kg and was launched on April 19, 1975. Since then, the Indian Space Research Organization has witnessed a mixed-bag of success and failure. It has successfully carried out more than 40 space missions, during the last four decades, in the area of space sciences, spacecraft technologies, space applications and launch vehicle technologies. The following paper discusses the configuration and objectives of a few of those missions.

INSAT series

The INSAT satellites are an operational multipurpose series of satellite catering to the needs of three different services: Television broadcasting, communications and meteorology. The INSAT project envisages the satellite's design, development, placing in orbit management and control of the satellite during its operational phase and the development and installation of associated ground segment facilities for controlling the satellite, monitoring the performance of its payloads and for full utilization of the satellite's capabilities.

The INSAT 1 series



*Fig 1: The INSAT 1A geostationary satellite
(http://www.skyrocket.de/space/img_sat/insat-1a__1.jpg)*

The INSAT 1A satellite was built by Ford Aerospace and launched by Delta on April 10th, 1982 to provide India with geostationary meteorological and communications services. It took 12 days to deploy the C-band antenna. When the solar panel failed to fully unfold, the S-band transponder overheated, which degraded the television and radio service, and the power shortage resulted in the meteorological instruments shutting down on 13th August. It expended its propellant attempting to recover on September 4th after losing Earth-lock caused by unanticipated moon interference and was deactivated two days later.

INSAT 1A suffered anomalies in deploying its antenna. Initially the antenna failed to deploy completely, but after it had heated up in the sunlight it was shaken loose by firing its thrusters. It soon became apparent that faulty propellant-isolation-valve control circuit would cause the satellite to exhaust its attitude control gas long before its 7 year lifetime, but this became irrelevant in Sept when the satellite was lost. As it was coming out of eclipse, one of its Earth sensors was deliberately switched off because the sun would be within its field of view. However, controllers failed to realize that as a result of a yaw-error built up by the absence of the solar sail, the full moon would intrude into the field of view of the other earth sensor, which would protect itself by switching off. With both sensors off, the attitude drifted sufficiently to break the narrow-beam command link, and as the contingency logic did not include a switchover to an omni-directional antenna, the satellite was lost.



Fig 2: INSAT 1B (<http://upload.wikimedia.org/wikipedia/commons/thumb/3/3c/STS008-33-1100.jpg/180px-STS008-33-1100.jpg>)

INSAT 1B was ejected from its cradle in the payload bay of STS-8 on 31st Aug 1983, the shuttle crew heard a clink during the ejection process but the satellite sailed away apparently unscathed riding its solid perigee kick motor. On achieving GEO orbit, it took several weeks to flatten out its segmented solar panel. At the end of its seven year nominal mission the satellite was relegated to serving as an in-orbit spare, because one of its two amplifiers had suffered a drastic reduction in gain and its nickel-cadmium batteries had failed. (*Space Systems Failures – David M Harland, Ralph D Lorenz*)

INSAT 1C was launched by Ariane 3 on 21st July 1988. It also had difficulty in deploying its solar panel. Shortly thereafter, a short between the external portion of the solar array drive and the array itself wiped out one of the two power buses, thereby denying the satellite six of its 12 C-Band transponders and one of two S-Band transponders. It was abandoned on 22nd November 1989 when it lost earth-lock. Launched by Ariane 3 on 3 June 1997, INSAT 2D suffered a short circuit on 1 October that caused it to lose earth lock, prompting it to be written off.

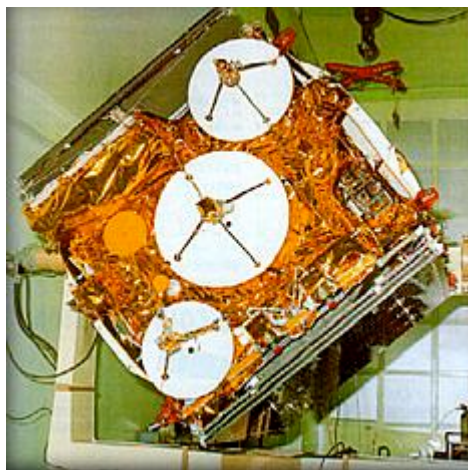


Fig 3: INSAT 1C (http://www.geocities.com/hari_ghk/insat.htm)

The Insat-1C satellite was launched on 21 July 1988 from Kourou for location at 93.5°E to bring the INSAT series up to full capacity. Half of the 12 C-band transponders and its two S-band transponders were lost when a power system failure knocked out one of the two buses, but the meteorological earth images and its data collection systems were both fully operational. Earth lock was lost 22 November 1989 and the satellite was abandoned. The Insat-1C failed during the last of a series of major solar and geomagnetic storm events of this memorable year. Sometime between October 19th and November 6th these storms caused major increases in energetic protons at energies above 10 MeV. On November 15th another powerful solar blast was detected on ground-level neutron monitors, and at the end of November another major solar flare, rich in high-energy protons, was recorded. The failure of INSAT 1C put even more emphasis on the success of INSAT 1D.



Fig 4: INSAT 1D (<http://www.st.northropgrumman.com/astro-aerospace/SiteFiles/siteimagesdirectory/INSAT1D.jpg>)

INSAT 1D was to be deployed by a shuttle. When it was on the pad on 19 June 1989, a crane hook tangled with cables smashed into the satellite, destroying its C-band antenna. Ford Aerospace said that it could be fixed for 10 million after initially writing it off. While it was undergoing repairs at Palo Alto, California, the facility was shaken with an earthquake which added another 150,000\$ to the repair bill. It was finally launched on 12 June, 1990 and operated for 5 years.

(Two roads into Space: the Japanese and Indian space programmes. B. Harvey, Springer-Praxis, 2000.)

The INSAT-2 satellites

The experience gained from INSAT-1s, particularly the post-launch difficulties with them, had helped ISRO in developing the INSAT-2s. These satellites were nearly twice as big and more advanced than INSAT-1s. The INSAT-2 project was started in 1985. ISRO had to build various facilities including the Large Space Simulation Chamber (LSSC) to test satellites of 4-m width and 5m height and an 1100 cubic meter acoustic chamber. LSSC can simulate 2173°C and provide hard vacuum (hundred thousandth of a millibar) and solar radiation conditions. Only about half a dozen such facilities exist around the world (The Hindu, 1 July, 1992)

(Competence building in complex systems in the developing countries: the case of satellite building in India - A. Baskaran, 24 March 2000)

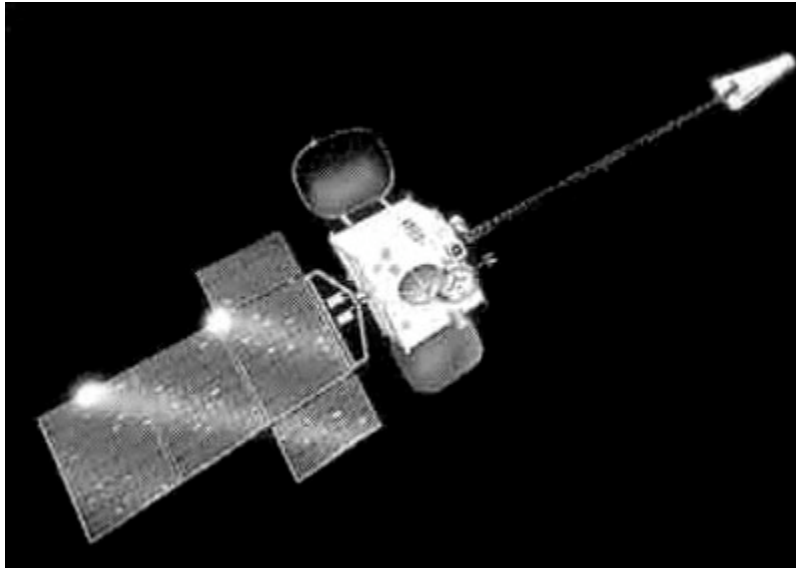


Fig 5: INSAT 2A and 2B(http://www.skyrocket.de/space/img_sat/insat-2a_1.jpg)

The 2nd generations of INSAT satellites (INSAT-2 series) were started from July 1992 with the successful launch of the first satellite of the series (INSAT-2A) on 10th July 92.

Insat-2A, 2B, are multi-purpose satellites for telecommunication, television broadcasting and meteorological services. They carry seventeen transponders - 12 operating in the normal C-band frequency and 6 in the lower extend C-band. Seven of the normal C-band transponders have wide beam coverage and the remaining have zonal coverage.

For meteorology, they feature a Very High Resolution Radiometer (VHRR) with 2 km resolution in visible band and 8 km resolution and water vapor band. Charge Coupled Device (CCD) camera operating in visible, near infrared and shortwave infrared band with 1km resolution.

Insat-2B went out of service on 7th November, 2000. It had been launched into a GEO orbit on 22nd July 1993. The satellite first lost its attitude control system, which consisted of four reaction wheels and thrusters which were in a 3-axis spin stabilized format, on 3rd November and then again a few days later. It was immediately decommissioned after the second incident as the failure could have occurred anytime again. It was later deorbited after a few years.

In March, 1994, India selected Arianespace to launch INSAT 2C in 1995 and INSAT 2D in 1996. The design lifetime was nine years. The spacecraft was similar to the earlier INSATs but was 200 kg heavier at launch (2,100 kg). It was launched into a GEO orbit and carried larger solar arrays for 1.6 kW of electrical power. The communications payload consisted of 12 C-band, 6 extended C-band, 3 Ku-band, and 2 S-band transponders plus a new low-power C-band transponder for a mobile communications feeder. Insat-2D, in addition to carrying communication transponders in Insat-2A and 2B,

incorporated Ku-band transponders for business communication, extended coverage C-band transponders to enable TV programme outreach beyond Indian boundaries catering to the population from South East Asia to the Middle East and transponders for mobile service. It did not have the meteorological payload. Insat-2C and Insat-2B are co-located in the geostationary orbit thus enabling efficient use of allocated orbital slots. It had an attitude control system which was 3-axis stabilized.

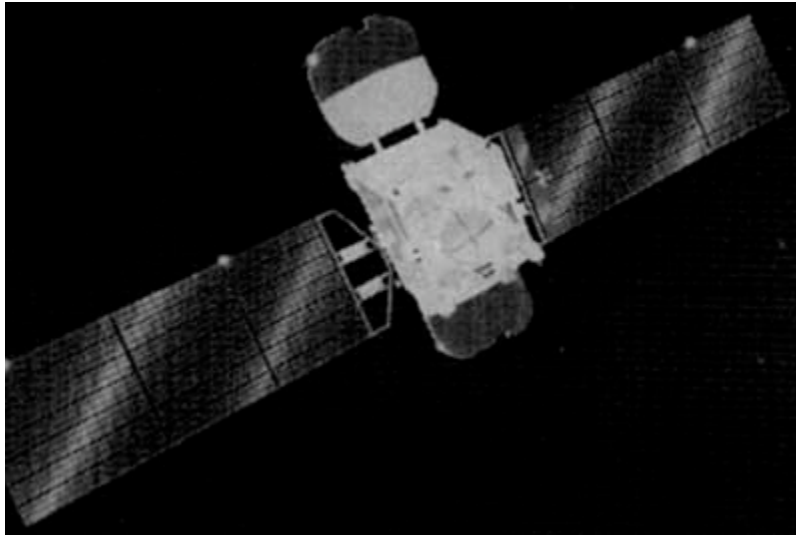


Fig 6: INSAT 2C and 2D

(http://space.skyrocket.de/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/insat-2c.htm)

Launched in June 1997, INSAT-2D became inoperable since October 4, 1997, due to total power loss. Although the loss of 12 C-band transponders and 6 XC-band transponders was partially offset by the acquisition of an in-orbit satellite, Arabsat-1C (designated as INSAT-2DT), the absence of XC-band on INSAT-2DT meant that the requirements of business organizations, corporate networks and other closed user groups (CUGs) such as the National Stock Exchange (NSE) and the Reserve Bank of India that rely on VSAT communications, could be met only by launching INSAT-3B ahead of INSAT-3A. INSAT-2E, which was launched in April 1999, did not have XC transponders.

For INSAT-2D, ACE magnetometer data showed a sharp rise in solar wind strength on October 1 followed by a persistent magnetic field intensity lasting a full day before subsiding again. The Earth-orbiting GEOTAIL satellite also noted a sharp change in the local energetic particle conditions as well as geomagnetic field strength. All of these are consistent with the arrival of the September 27 CME around October 1 at the time the INSAT-2D began having its problems.

The on-board propulsion system employed in the INSAT satellites is a unified bipropellant system. The liquid apogee motor used for orbit raising operations, and the bank of attitude and orbit maneuver thrusters are supplied with the propellants, from the

same on-board propellants tanks. The attitude determination on ground is carried out with the raw/onboard pre-processed star sensor data or earth sensor data and precision data from gyro. Periodic gyro calibration in-orbit, capability to uplink error matrices due to misalignments, etc., provide better attitude knowledge. Quaternion approach of representing attitude has been adopted in missions where processor based Attitude Orbit Control Electronics (AOCE) has been flown. The attitude determination accuracies achieved are better than $\pm 0.01^\circ$.

INSAT missions depend on star sensors and gyros for meeting the stringent specifications of targeting accuracy, pointing and location accuracy. The contribution from orbit error is minimized by employing satellite positioning system onboard which locks onto GPS constellation to provide pseudo range and range-rate information which is used for orbit information generation onboard which in turn is used for attitude information generation, orbital events generation like eclipse entry/exit timings, ephemeris generation, PAA look angles generation and so on. The importance of gyros is crucial for meeting stringent mission specifications. Gyros misalignment and scale factors contribute significantly in the overall error budget. Hence, gyro calibration is an important activity to be carried out in the mission operations phase to determine the error matrices and uplink the same to the spacecraft. In order to contain the temperature variations to ensure stability, gyros have automatic temperature controllers, which enable gyro to remain within $\pm 1^\circ\text{C}$ from the nominal on-orbit temperature, which also could be selected from ground.

Out of the four INSAT-2 satellites, all were successful except INSAT 2D. INSAT 2C was qualitatively different from 2A or 2B, especially when considering the payload. The successful launch of INSAT 2A, 2B, and 2C clearly demonstrated India's capability to build complex and sophisticated communication satellites. Some capacity of the next satellite in the series, INSAT-2E, already has been leased to INTELSAT (*DOSA, 1996-97, p. 19*). It clearly shows that India acquired a high level of capabilities that are comparable to other nations that are more advanced in this field.

Later, the INSAT 2E, INSAT 3 series and INSAT 4 series were successfully deployed into space and are completely operational even today.

CHANDRAYAAN – 1

Chandrayaan-1 mission aims at mapping of the Moon surface with various instruments to study the topography and chemical composition. The mission planning and operations aspects of Chandrayaan-1 are discussed below:

- The spacecraft main bus is configured to accommodate five Indian instruments and six foreign instruments.

The Moon Impact Probe will be jettisoned from the main orbiter after attaining the desired lunar orbit with assured ground visibility at the required prime meridian.

- The data collection plan from each instrument follows the spacecraft power constraints, orientation requirements of individual instrument, data readout capabilities and constraints of ground stations.
- The science data return is maximized by having two data reception stations, one in Bangalore and the other in Maryland, USA, with the third station in Goldstone, USA filling the visibility gap.
- A comprehensive TTC Network (ISTRAC + external agencies) ensures almost continuous visibility of the spacecraft in all phases of the mission. These stations will also enable X-band systems checks en-route to Moon.
- The Indian Space Science Data Centre (ISSDC) facilitates the data processing, archival and dissemination functions. Data dissemination takes place through dedicated links and high-speed Internet links.
- The Indian Deep Space Network (IDSN) stations consisting of an 18 m-diameter antenna and a 32-m diameter antenna serve the mission needs in terms of TTC and data functions.
- The launch window studies take into account the spacecraft constraints and the spacecraft – Moon geometry at the time of lunar orbit insertion. Two opportunities in a lunar month are available for launch. Any shift in launch date or launch time (2UT or 14UT) on a day has overall fuel penalty. This has been budgeted and about 6 kg of fuel allocated to account for delays in launch.
- Attitude steering is introduced during the orbit maneuvers.
- The lunar orbit insertion is planned to be achieved with face-on geometry and ensuring visibility from Indian ground stations.
- The mission operations system inherits many features from the IRS and INSAT system. However, new ground stations, IDSN, ISSDC, payload operations centers and outreach activities are being planned for the first time.
- Detailed pre-launch simulations plans, development of software simulators, hardware simulators and integrating the entire mission operations system with completion of test and evaluation of all hardware software and procedures are new challenges to ISRO.
- The noon/midnight orbit, when the Sun vector is parallel to orbit plane, is chosen for imaging operations with an allowed excursion of $\pm 30^\circ$ of Sun aspect angle. One imaging season will be for the duration of two months.
- In order to generate adequate power throughout the mission life, two strategies are adopted: (a) the panel is canted at an angle of 30° , with respect to positive pitch in pitch-yaw plane, (b) solar panel is flipped by 180° , about pitch axis at dawn/dusk orbits and to give 180° yaw rotation at noon/midnight orbits.
- Orbit maintenance is required to maintain the altitude above the Moon surface and is executed once in 14 days during face-on orbit conditions. Onboard sequencer takes care of maneuver preparation, execution and normalization.
- Star sensor used for gyro updates when occulted by Earth or Sun is deselected in favor of non-occulted redundant star sensor.

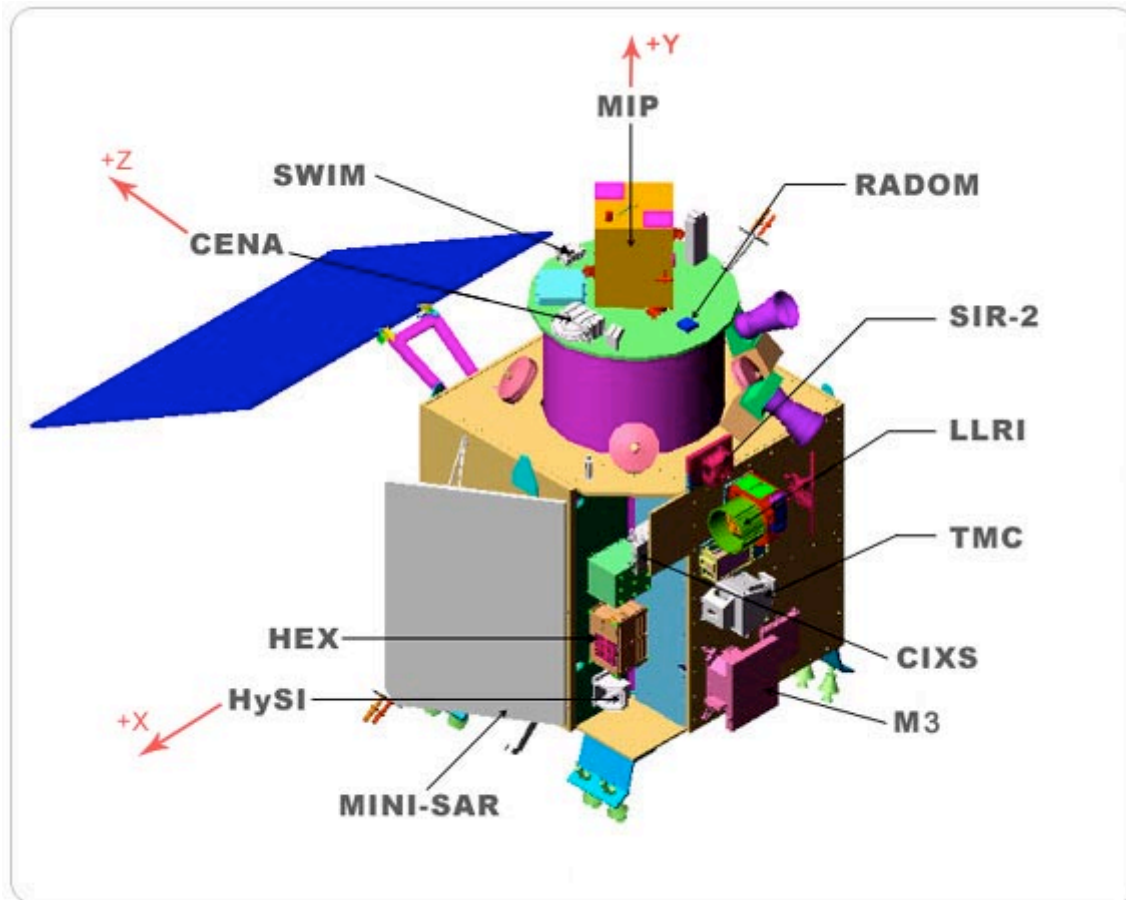


Fig 7: The Chandrayaan 1 spacecraft with all its 11 scientific payloads
<http://www.chandrayaan-i.com/images/space3d01ab.jpg>

The spacecraft

- Weighs 1304kg at launch and 590kg at lunar orbit
- 3-axis stabilized using 2 star sensors, gyros and four reaction wheels and attitude control thrusters.
- Accommodates 11 scientific payloads. The scientific payload has a total mass of 90 kg and contains five Indian instruments and six foreign instruments.
- Employs a X-band, 0.7m diameter antenna for payload data transmission. The antenna employs a dual gimbal mechanism to track the earth station when the spacecraft is in lunar orbit.
- Has 3 solid state recorders (SSRs):
 - 1) SSR-1 – storage of science payload data with 32 GB capacity
 - 2) SSR-2 – storage of spacecraft attitude information (gyros and star sensors) and other auxiliary data with 8 GB capacity.
 - 3) M3 – Moon Mineralogy Mapper with 10 GB capacity.

Attitude Control System

The gyros, reaction wheels and 2 star trackers will act as the input devices. The thrusters will perform fuel burns to change the spacecraft's trajectory and attitude, they may be

used in conjunction with reaction wheels or control moment gyros to offload momentum biases accumulated over time. Chandrayaan-1 will use bipropellant integrated propulsion system. The propulsion system consists of a unified bi-propellant system for orbit raising and attitude control. Disturbance torques acting on the spacecraft sometimes change the angular momentum of the wheel and when the wheel speed reaches the upper limit external torquing is used to bring down the wheel speed. This momentum dumping operation can be done by using either magnetic torquers or thrusters as actuators. Orbit control using thrusters, corrects the orbit drifts introduced by perturbing forces acting on the spacecraft. As reaction wheels cannot handle large attitude errors introduced during orbit control, all the three axes are controlled by thrusters. Further, provision exists for biasing the pitch and roll error outputs to compensate for long term drifts/offsets.

Its attitude-control system will normally maintain attitude without thrusting, using its reaction wheels, to permit long undisturbed tracking runs; however, wheel desaturation will occasionally be necessary, and since the Moon has no useful magnetic field the standard low-Earth-orbit approach of using magnetorquers for desaturation will not work, so occasional attitude control thrusting will be needed.

Chandrayaan 1 uses a similar reaction wheel alignment to the Indian Remote Sensing Satellite (IRS), which was launched in a series as well. It employs three orthogonally placed reaction wheels for its attitude control. A fourth skewed reaction wheel is provided for redundancy in case of failure in any one of the wheels. Based on failure, the skewed wheel takes over the function of the failed wheel by appropriate gain matrix selection which not only assigns the function of the failed wheel to the skewed wheel, but also ensures the cancellation of the disturbance caused by the skewed wheel torquing to the other two working wheels. The wheel failure is likely to result in attitude loss, and attitude reacquisition with very limited ground support (ground stations limited to Indian territory) is a very difficult task. To avoid this attitude loss, an algorithm has been developed and implemented on a microprocessor to detect the failure and identify the failed wheel, to suitably select the gain for the skew wheel, and to bring it into operation before the spacecraft attitude errors become significant.

The spacecraft is three-axis stabilized in polar circular orbit. Its payload axis pointing towards local vertical is achieved by employing three reaction wheels, one for each axis, yaw, roll, and pitch in a zero momentum configuration. The Earth sensors provide continuous information of roll and pitch errors whereas the yaw information is obtained from a gyro based reference. This gyro is updated twice an orbit near the poles, taking yaw information from the Sun. The controller is a pulse width pulse frequency modulator (PWPFM) employing pseudo rate damping techniques to obtain a highly stable configuration as demanded by the remote sensing payload. A skew wheel is provided, making an angle $\tan^{-1} \pi/2$ with all the three axes (Fig. 8). This wheel provides redundancy to the failure of any of the three wheels. (*Auto Reconfiguration of Reaction Wheels in IRS - P.S.GOEL, V.K.AGRAWAL, A. KRISHNAN, J.S. UPADHYAYA, 1985*)

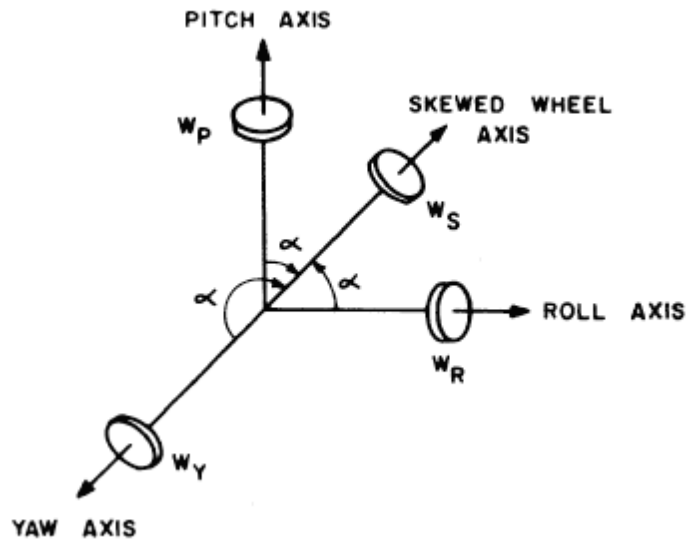


Fig 8: Reconfigurable reaction wheel system (Auto Configuration of Reaction Wheels in IRS – P.S.Goel, V.K.Agrawal, A.Krishnan, J.S.Upadhyaya, 1985)

Lunette is a 5 kg gravity-mapping payload, including a 3.5 kg subsatellite derived from the current CanX nanosatellites. It is meant to fly on one of the larger lunar-orbiter missions now being planned. The subsatellite includes attitude control, imaging, station-keeping/maneuvering propulsion, and a radio transponder for tracking by the electronics package on the parent spacecraft.

Originally, Lunette was originally proposed for India's Chandrayaan-1 mission (Bhandari *et al.*, 2003), in response to ISRO's Announcement of Opportunity for international payloads. The proposal was well received and was included on ISRO's initial "short list", but the extremely tight proposal schedule ultimately made it impossible to arrange firm funding quickly enough. (The cost of the Lunette payload should be able to come in well under \$10M.)

Chandrayaan-1 will orbit the moon at an altitude of 100km for a period of 2 years. The Indian Space research Organization is confident of launching Chandrayaan sometime in July 2008. This will be followed by a Chandrayaan-2 mission, which will include a spacecraft and a rover with wheels landing on the moon's surface and collecting rock samples, performing chemical tests and transmitting the data back to the hovering mother spacecraft. (Space mission planning and operations - V. Adimurthy, M. Y. S. Prasad, and S. K. Shivakumar)

Trajectory design and carrying out maneuvers to achieve the desired lunar trajectory minimizing the fuel requirement is an important aspect of this mission. The methods can be broadly divided as direct and indirect transfers (Beisbrock and Janin 2000; Adimurthy 2003). A traditional direct transfer to the Moon essentially puts the spacecraft into a Lunar Transfer Trajectory in one go from a low Earth orbit. Other unconventional

methods employ either highly elliptic phasing orbits, or transfer via Lagrangian points to reach the Moon. In the post-Apollo era, the unconventional methods are being increasingly considered for lunar mission design because of their low-energy requirements. All these approaches were evaluated for the Indian lunar mission.

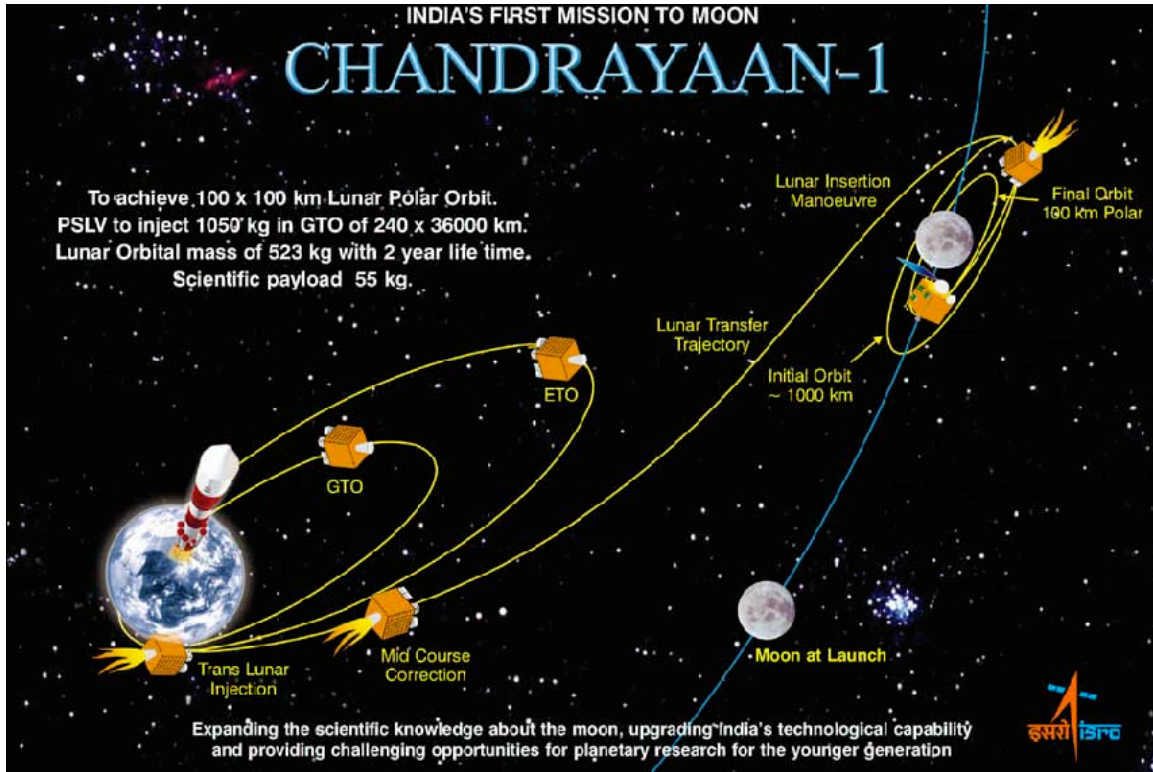


Fig 9: Launch of Chandrayaan 1, Lunar Trajectory Transfer and Insertion into Lunar Orbit (<http://www.isro.org/chandrayaan-1/>)

Methods of reaching lunar orbits

The traditional direct transfer

In this approach, the mission begins from a parking orbit around the Earth. Then, for Lunar Transfer Trajectory the apogee of the parking orbit is raised to the Moon's distance or higher. Duration for this transfer is about 5 days. The perigee burn can be accomplished in a single burn or multiple burns of smaller duration. An important criterion for the mission is that the spacecraft be launched when the Moon's declination is less than the inclination of the parking orbit. All the lunar missions from 1960s to the 1980s used this traditional approach. For direct missions like this the velocity requirement for traveling from the parking Earth orbit to Lunar Transfer Trajectory is of the order of 3.1 km/s. This normally requires separate propulsive stage in the launch vehicle.

Transfer via GTO/EPO

One of the primary ways to reduce the launch cost is to reduce the total delta velocity requirement. Two possible options are available, namely, utilizing energy from other celestial bodies or launch from an EPO like GTO. Since the energy of GTO is

considerably higher than that of a Low Earth Orbit, it leads to savings on the Lunar Transfer Trajectory (LTT) requirements. Thus the launch vehicle itself provides considerable energy and that required from the spacecraft is correspondingly less. However, this approach implies a limitation in the launch opportunity since a plane change is required because the apsidal line of GTO will be normally near the equatorial plane. In one lunar month, the Moon will arrive twice near to its node, and this determines the launch window for the lunar mission via EPO. Transfer from a highly elliptic parking orbit greatly simplifies the developmental requirements and is the best-suited approach for PSLV.

Weak stability boundary (WSB) transfers

We know that reduced velocity requirement reduces the mission cost. However, the Lunar Transfer Trajectory velocity requirements cannot be reduced beyond a certain value. So the velocity requirements for lunar orbit insertion could be reduced further by reducing the requirement through arriving at the Moon with a low relative velocity. This can be achieved by taking the spacecraft to the region of Lagrangian points of the Earth–Sun system. A small maneuver within such a region can lead to a significant change in the lunar arrival conditions. This is known as the Weak Stability Boundary approach. However, the disadvantages of the weak stability boundary method are that **(a)** the time taken to achieve lunar orbit is several months (instead of a few days for direct methods), **(b)** the spacecraft is required to traverse large distances of the order of four times the lunar distance, and this puts a very high burden on the communication power requirements. If these problems can be handled, the WSB methods offer a highly energy efficient way to reach the Moon. This type of transfer was used in the Japanese Hiten spacecraft.

(Launch strategy for Indian lunar mission and precision injection to the Moon using genetic algorithm - V Adimurthy□, R V Ramanan, S R Tandon and C Ravikumar)

Lunar Orbit Insertion (LOI)

The lunar orbit insertion is the most critical maneuver in the mission and needs to be carried out autonomously as it may occur at the point behind the Moon without RF contact with the Earth station. Any variation in the time or position will result in a huge fuel penalty or the lunar capture may not take place. The success of the entire mission depends on this important maneuver. The last calibration of the gyros prior to the Lunar Orbit Insertion (LOI) is most crucial as this information is used for holding the attitude during the LOI burn and any uncertainty emerging thereof will have a direct fuel penalty. It is desirable that the LOI burn and all other major burns be conducted during station visibility in order to permit reactions to any contingency. However the spacecraft design should have adequate capabilities onboard like delayed command timer for conducting burns in the blind when necessary. Furthermore, it is necessary to support this operation by adequate onboard autonomy, which has the capability to reconfigure the spacecraft and continue the maneuver even in case of failures. Onboard accelerometers are used to determine the extent of realization of the maneuver. The LOI plan consists of multiple burns. The first LOI burn is targeted such that it is collision free and ensures successful capture of the spacecraft by the Moon. Subsequent LOI burns are carried out to achieve 100 km circular orbit.

Onboard autonomy is very important during the lunar orbiting phase of the mission to get data segments recorded during attitude loss and contingencies, since procuring DSN support from other network is expensive. The reconfiguration and a certain amount of fault-tolerant features need to be built in as the lunar spacecraft may not carry identical redundancies for some functions. Hence graceful degradation employing other redundant systems has to be incorporated like calibration of gyros, using star sensor, needs to be done autonomously using onboard software. The driving of onboard antenna for payload data link also has to be carried out in open loop autonomously. Payload operations and orbit maintenance maneuvers are to be sequenced properly onboard without ground prompting to minimize data outages. It is also necessary to have overrides for all onboard autonomous functions, in case of failures.

(Imaging and power generation strategies for Chandrayaan-1 - Ananth Krishna, N S Gopinath, N S Hegde and N K Malik)

References

1) *The following link - <http://www.youtube.com/watch?v=ipBOotJDJ1k> is an animated video about the Chandrayaan 1 mission and its specifics.*

2) *Lunette: Lunar Gravity Mapping With A Nanosatellite - H. Spencer, K. A. Carroll, J. Arkani-Hamed, R. E. Zee*

3) *Recent disasters during launch and operations of commercial satellites - Fordyce, S. W.*

4) *http://space.skyrocket.de/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/insat-3d.htm*

5) *Indian Space Research Organization (ISRO) – www.isro.org*

6) *(Space Systems Failures – David M Harland, Ralph D Lorenz)*

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8) *(Competence building in complex systems in the developing countries: the case of satellite building in India - A. Baskaran, 24 March 2000)*

9) *(Auto Reconfiguration of Reaction Wheels in IRS - P.S.GOEL, V.K.AGRAWAL, A. KRISHNAN, J.S. UPADHYAYA , 1985)*

10) *(Space mission planning and operations - V. Adimurthy, M. Y. S. Prasad, and S. K. Shivakumar)*

11) (Launch strategy for Indian lunar mission and precision injection to the Moon using genetic algorithm - V Adimurthy, R V Ramanan, S R Tandon and C Ravikumar)

12) (Imaging and power generation strategies for Chandrayaan-1 - Ananth Krishna, N S Gopinath, N S Hegde and N K Malik)