Imaging and power generation strategies for Chandrayaan-1

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The Chandrayaan-1 mission proposes to put a 550 kg lunarcraft into Geostationary Transfer Orbit (GTO) using the Polar Satellite Launch Vehicle (PSLV) which will subsequently be transferred into a 100 km circular lunar polar orbit for imaging purposes. In this paper, we describe certain aspects of mission strategies which will allow optimum power generation and imaging of the lunar surface.

The lunar orbit considered is circular and polar and therefore nearly perpendicular to the ecliptic plane. Unlike an Earth orbiting remote sensing satellite, the orbit plane of lunar orbiter is inertially fixed as a consequence of the very small oblateness of the Moon. The Earth rotates around the Sun once a year, resulting in an apparent motion of Sun around this orbit in a year. Two extreme situations can be identified concerning the solar illumination of the lunar orbit, noon/midnight orbit, where the Sun vector is parallel to the spacecraft orbit plane and dawn/dusk orbit, where the Sun vector is perpendicular to the spacecraft orbit plane. This scenario directly affects the solar panel configuration. In case the solar panels are not canted, during the noon/midnight orbit, 100% power is generated, whereas during the dawn/dusk orbit, zero power is generated. Hence for optimum power generation, canting of the panels is essential. Detailed analysis was carried out to fix optimum canting and also determine a strategy to maintain optimum power generation throughout the year. The analysis led to the strategy of 180° yaw rotation at noon/midnight orbits and flipping the solar panel by 180° at dawn/dusk orbits. This also resulted in the negative pitch face of the lunarcraft to be an anti-sun panel, which is very useful for thermal design, and further to meet cooling requirements of the spectrometers.

In principle the Moon's surface can be imaged in 28 days, because the orbit chosen and the payload swath provide adequate overlap. However, in reality it is not possible to complete the imaging in 28 days due to various mission constraints like maximum duration of imaging allowed keeping in view the SSR sizing and payloads data input rate, time required for downlinking the payload data, data compression requirements and visibility of the lunarcraft for the Bangalore DSN. In each cycle, all the latitudes are swept. Due to the constraints mentioned, only 60° latitude arc coverage is possible in each orbit. As Bangalore DSN is the only station, half of the orbits in a day are not available. The longitudinal gaps because of non-visibility are covered in the next cycle by Bangalore DSN. Hence, in the first *prime imaging season*, only 25% of the prime imaging zones are covered, and an additional three *prime imaging seasons* are required for a full coverage of the Moon in two years. Strategy is also planned to cover X-ray payload coverage considering swath and orbit shift.

1. Introduction

The Indian Space Research Organisation (ISRO) is planning a mission to the Moon with a view to study chemical and mineralogical characteristics of the lunar surface. It is proposed to put a 550 kg lunarcraft into Geostationary Transfer Orbit (GTO) using the Polar Satellite Launch

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Vehicle (PSLV) and subsequently transfer it into a 100 km circular lunar polar orbit for imaging purposes. The payloads and science goals for Chandrayaan-1 mission are discussed briefly by Goswami *et al* (2005); Bharadwaj *et al* (2005); Kiran Kumar and Roy Choudhury (2005a, b). Remote sensing the Moon within a given set of lunarcraft orbits requires a well planned imaging strategy. This paper brings out a summary of studies carried out on a few aspects of the lunar mission such as orbital characteristics, visibility analysis, general outline of the manoeuvers, features regarding onboard autonomy, details of an optimal strategy for power generation, and formulation of strategies for imaging the entire lunar surface by various payloads in view of various mission constraints.

2. Orbital characteristics of lunar mission

2.1 *Lunar orbital geometry*

As is well known, the motion of the Moon results from a complex balance of the gravitational forces mainly due to the Sun, Earth and the Moon itself. Table 1 provides details of the Moon's orbit.

2.2 *Orbit-arc coverage*

Orbital-arc visibility depends upon the Moon–Earth and orbital plane geometry. Figure 1 shows the Earth–Moon geometry. A maximum of 12 hours per day is visible twice in a cycle of 28 days when the Moon–Earth vector is perpendicular to the orbital plane. Figure 2 provides the lunar orbit visibility from Bangalore station.

The lunarcraft orbits around the Moon 12 times in one Earth's day. Of these 12 orbits only 5 to 6 orbits are visible from the city of Bangalore where the Deep Space Network (DSN) is proposed to be set up.

Table 1. *Details of the moon's orbit.*

Characteristics	Values
Revolution period and axial rotation period	27.321661 ephemeris days
Synodic period (new moon to new moon)	29.53059 ephemeris days
Apogee	406700 km largest
	405508 km (mean)
Perigee	356400 km smallest
	363300 km (mean)
Mean orbital velocity	1.023 km/s
Period of regression of nodes	18.5995 years
Eccentricity of orbit	0.0549 (mean)
Inclination of orbit to the ecliptic	$5^\circ\ 8'\ 43''$ (mean)
Inclination of orbit to the Earth's equator	$28^\circ\ 35'$ maximum
	$18^\circ\ 21'$ minimum
Inclination of lunar equator to the ecliptic	$1^\circ\ 32'\ 40''$
Inclination of lunar equator to orbit	$6^\circ\ 41''$
Rotational velocity at equator	16.65 km/hr (mean)
Diameter	3470 km (polar)
	3476 km (equatorial)
Oblateness	0.0002
Apparent diameter from the Earth	$31'\ 5''$ (mean)
Escape velocity	2.38 km/s
Optical liberations, selenocentric displacement	$\pm 7.6^\circ$ (longitude)
	$\pm 6.7^\circ$ (latitude)

2.3 *Tracking support and orbit determination*

The S-band network comprising of Indian stations and worldwide S-band network is capable of

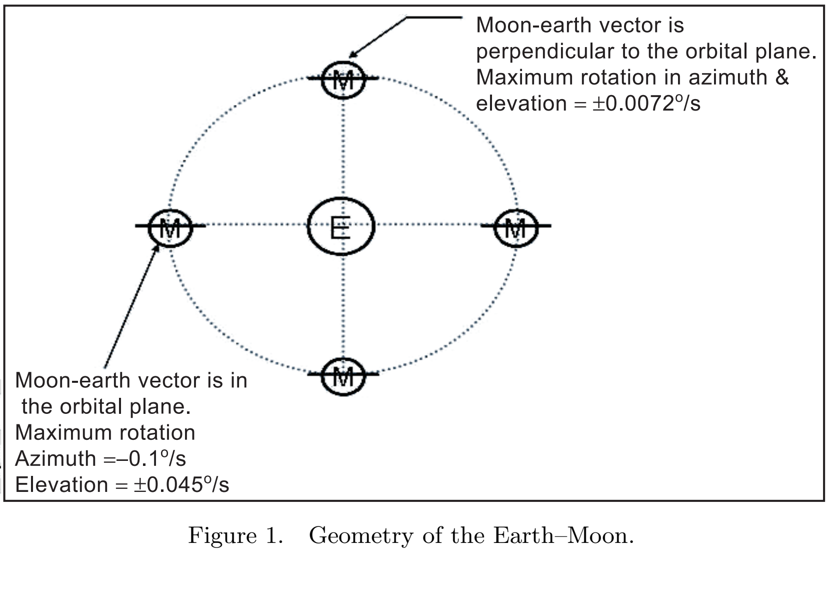

Figure 1. Geometry of the Earth–Moon.

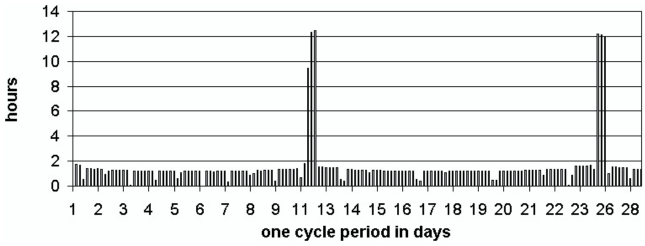

Figure 2. Lunar orbit visibility from Bangalore station.

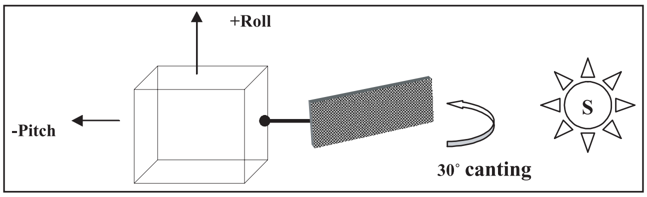

Figure 3. Solar array canting geometry.

providing near-continuous visibility of the lunarcraft operations from launch to a slant range of 100,000 km in the LTT (Lunar Transfer Trajectory) phase. This range covers both the phasing loops and the early leg of LTT. DSN stations are required to support the mission operations when this range is exceeded. Lunar mapping phase orbit determination will primarily make use of range and range-rate data from the Indian DSN. The orbit determination accuracy requirement during LTT is about 10 km in position and better than 1 km in position during lunar mapping phases. Tracking data from S-band network, i.e., range, range-rate and angles are used in the early phase and later, the DSN stations range and accumulated range-rate are used for covering LTT and lunar orbit insertion phases.

2.4 *Perigee manoeuvers*

It is planned to insert the spacecraft into the LTT using multi-burn strategy. This trajectory looks hyperbolic with respect to the Moon. The split burn strategy minimises gravity losses during the perigee burns and also provides the capability for assessing and calibrating the overall performance of liquid motor (LM) and attitude control system. Any deviation in the overall performance can be taken care of in the next firing. As the resultant penalties in terms of propellant are quite large, the need to assess the performance in almost real time is necessary. The use of accelerometers to provide cut-off for the propulsion system when the desired velocity increment is achieved is also envisaged. Additionally the orbit is determined using range, range-rate and angle data subsequent to the last burn in the split-burn strategy, and the orbit is propagated to check the projected periselene conditions. If the desired parameters at periselene are not obtained, then a small midcourse correction burn is carried out in LTT in order to minimise the total propellant required for achieving the final target orbit around the Moon. The additional propellant penalty for this mid-course correction depends upon the errors in the final LTT injection burn.

2.5 *Lunar Orbit Insertion (LOI)*

The lunar orbit insertion is the most critical manoeuver in the mission and needs to be carried out autonomously as it may occur at the periselene 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 manoeuver. 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 manoeuver even in case of failures. Onboard accelerometers are used to determine the extent of realization of the manoeuver. 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.

2.6 *Onboard autonomy*

Once the lunarcraft is launched, the perigee manoeuvers need to be carried out as per the determined plan, offering no flexibility in time and magnitude. The perigee manoeuvers are generally not visible to ground stations and need to be executed autonomously. The most important manoeuver of the mission, i.e., the lunar capture carried out near the periselene also may not be fully visible to the DSN stations. As all these orbit manoeuvers are carried out without direct ground contact, it is necessary to have adequate onboard autonomy to reconfigure and continue the manoeuver.

Onboard autonomy is also necessary during the lunar orbiting phase of the mission to get data

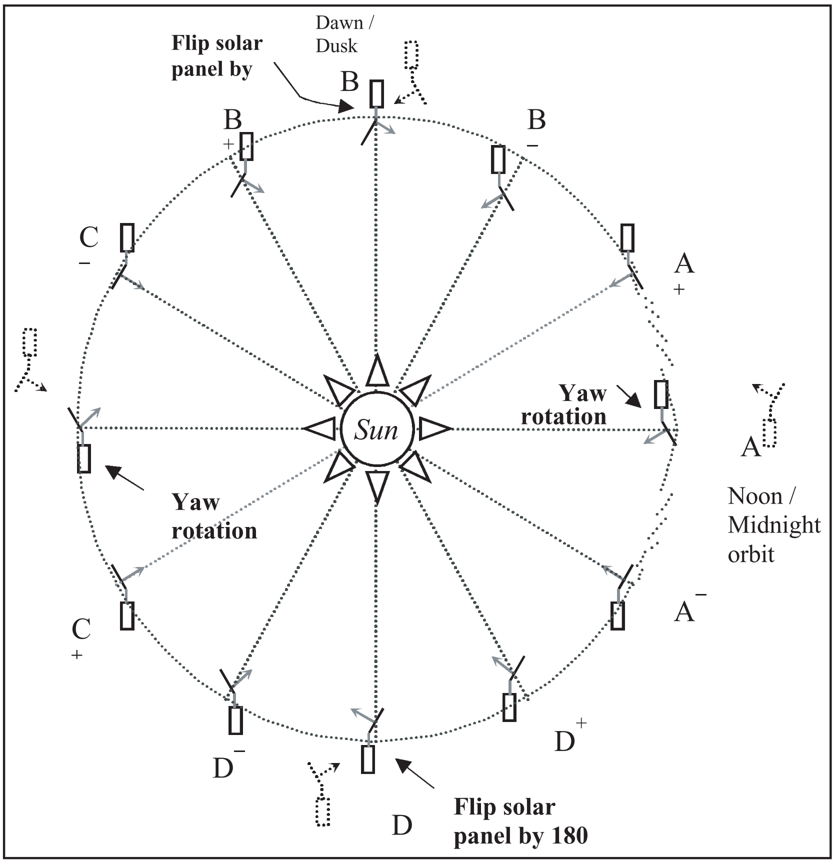

Figure 4. Solar array orientation strategy over a year.

Table 2. *Sun incidence on the solar panel.*

Position	Solar panel rotation (about Pitch)	Satellite rotation (about Yaw)	Sun incidence on the panel
A^-	–	–	0°
A	–	180°	30°
A^+	–	–	0°
B^-	–	–	30°
B	180°	–	60°
B^+	–	–	30°
C^-	–	–	0°
C	–	180°	30°
C^+	–	–	0°
D^-	–	–	30°
D	180°	–	60°
D^+	–	–	30°

segments recorded during attitude loss and contingencies, since procuring DSN support from other network is expensive. Reconfiguration and a certain amount of fault-tolerant features need to be built in. Lunarcraft may not carry identical redundancies for some functions; hence graceful degradation employing other redundant systems has to be incorporated. 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 manoeuvers are to be sequenced properly onboard without ground prompting to minimise data outages. It is also necessary to have overrides for all onboard autonomous functions, in case of failures.

3. Strategy for solar power generation

If the solar panels were not canted, situations would arise such that during noon/midnight orbit 100% power is generated, whereas during dawn/dusk orbit zero power is generated. Hence canting of the panels is essential. Optimum canting with respect to positive pitch in Pitch–Yaw plane was found by orbital analysis and is shown in figure 3.

The orientation of the spacecraft at various points during a year is shown in figure 4 and the corresponding Sun incidence angle is shown in table 2. It is seen that if the spacecraft is configured as in position A, at noon/midnight orbit, the panel normal makes 30° angle with the Sun. If the same orientation is maintained until the satellite reaches dawn/dusk orbit at position B, the panel normal

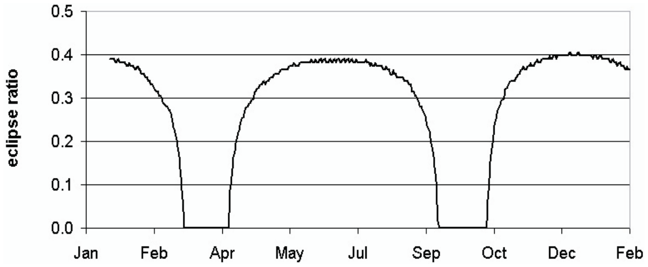

Figure 5. Eclipse factor.

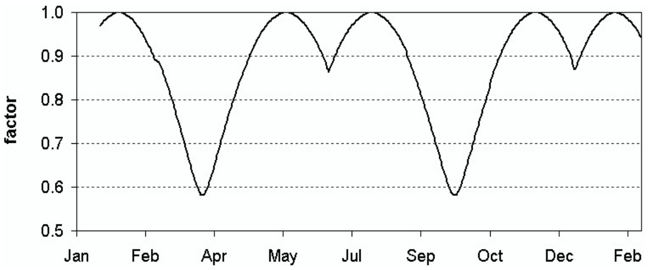

Figure 6. Power generation.

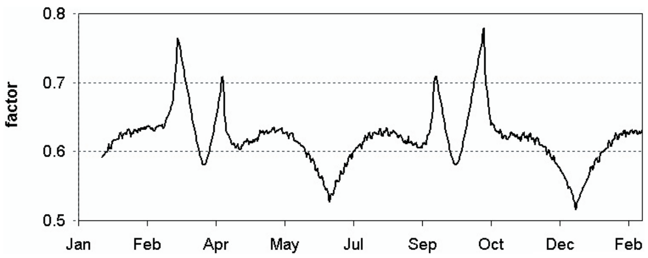

Figure 7. Average power generation.

makes 60° angle with the Sun's incidence. If continued further from position B to C, the panel normal becomes perpendicular to the Sun. In order to avoid this situation and to maintain optimum power generation at position B, the solar panel will be flipped by 180°, about pitch axis. Thus the satellite is maintained in this orientation until it arrives at position C and at C, the satellite is given a yaw rotation to optimise the power generation. Hence the strategy is to give 180° yaw rotation at noon/midnight orbits and flip the solar panel by 180° at dawn/dusk orbits.

It may be noted that, in all these orientations, the negative pitch face of the spacecraft does not look at the Sun directly, providing an anti-sun panel, much needed for thermal design and to meet cooling requirements of the spectrometer detectors.

For a 100 km altitude circular lunar orbit having a period of 118 minutes the average eclipse duration during periods of eclipses is 45 minutes and the longest eclipse duration is 48 minutes. The yearly variation of the eclipse factor is shown in the figure 5.

Considering the eclipse factor, the power generation profile for one year is shown in figure 6.

$$\text{Average power} = (\text{1-eclipse factor}) \times \text{power generated}$$

Average power generated over a year is computed as follows. Figure 7 shows profile of average power generated over the year.

4. Imaging strategy

The proposed orbit Chandrayaan-1 around the Moon is circular and polar and therefore nearly perpendicular to the ecliptic plane as shown in figure 8. The orbit plane shown is inertially fixed as a consequence of the very small oblateness of the Moon.

The Earth rotates around the Sun once a year, resulting in an apparent motion of the Sun around this orbit in a year. The solar incidence angle with respect to surface normal changes at about 1° per day. As a result, the ground trace of the orbit is illuminated with solar aspect angle within 30° at the Moon's equator for two months, once every six months. Hence the period of 2 months around noon/midnight orbit has been defined as the prime imaging season. During this period, ±60° latitude zone of the lunar surface (prime imaging zone) is covered. The Sun has a movement of 1.5° with respect to the lunar equator. Consequently, the illumination levels for the polar orbit are strongly dependent on the lunar latitude. Near-polar regions are poorly lit throughout the year and therefore 15 days immediately prior to and after the prime imaging season is earmarked for polar coverage (±60° to pole) by the imaging payloads. The ground trace during these 3 months is not altered.

Illumination conditions for prime imaging zone at 100 km altitude are met within ±1.5 months of noon/midnight orbit as can be seen from figure 8. The solar incidence angle with respect to the surface normal changes at about 1° per day at equator. Figure 9 shows the compound solar incidence angle variations as a function of latitude and season.

The following terms are defined to optimise complete lunar coverage by all the payloads.

- *Prime imaging season*: Season during which the solar aspect angle at lunar equator is within ±45°. It comprises 90 days centered around noon/midnight orbit suitable for optical imaging.
- *Prime imaging zone*: Region within ±60° latitude of lunar equator, sensitive to illumination

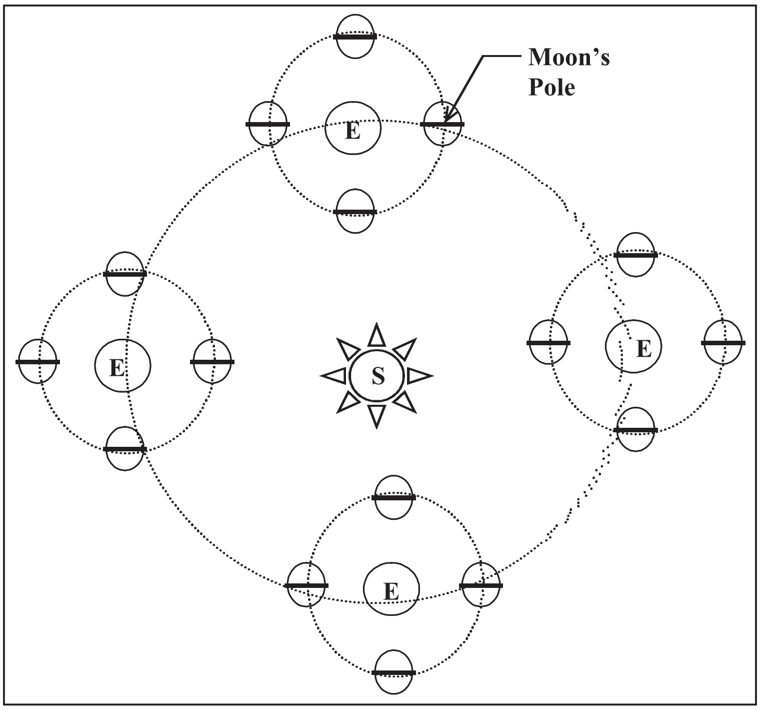

Figure 8. Schematic of the ecliptic plane, depicting relative motion of the Earth and the Moon in a year.

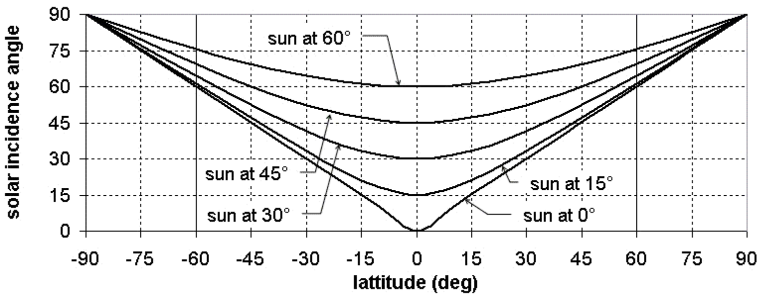

Figure 9. Solar aspect angle.

variation resulting from movement of the Sun over the imaging season. This zone is covered by imaging payloads within 60 days centered on noon/midnight orbit, restricting the solar aspect angle within ±30° with respect to the lunar equator.

- *Polar zone*: Polar zones on the Moon are poorly illuminated with grazing Sun rays and illumination levels are relatively insensitive to seasonal motion of the Sun (±1.5° w.r.t lunar equator). It is planned to cover these areas during the 15 days of prime imaging season when the Sun angle is between ±30° and ±45°.
- *Secondary imaging season*: Season in which the solar aspect angle at lunar equator is greater than ±45°. This season comprises 90 days centered on dawn/dusk orbit. During this period, payloads which are not dependent on ground illumination levels like mini-SAR, HEX, LLRI, SARA and RADOM are operated (Goswami *et al* 2005; Bharadwaj *et al* 2005; Kiran Kumar and Roy Choudhury 2005a, b).

4.1 *Prime imaging zone coverage*

Table 3 provides the orbital parameters of the lunarcraft Chandrayaan-1 at an altitude of 100 km around the Moon relevant for global imaging. The ground track shifts after every orbit by 32.6 km, due to the Moon's rotation about its own axis.

The orbital cycle of the lunarcraft is 28 days. The descending node selenographic longitudes are referred to as path numbers. Figure 10 shows the ground trace of the lunarcraft for one orbit. Since the selenographic inclination is 90° (polar orbit), the lunarcraft traces all the latitude regions, during each orbit.

Table 3. *Orbital details of the lunarcraft.*

Cycle days	28
Period	7053.06 s
Altitude	100 km
Inclination	90°
Equatorial distance between consecutive ground tracks	32.62 km
Payload swath	20 km
Overlap	3.64 km at lunar equator

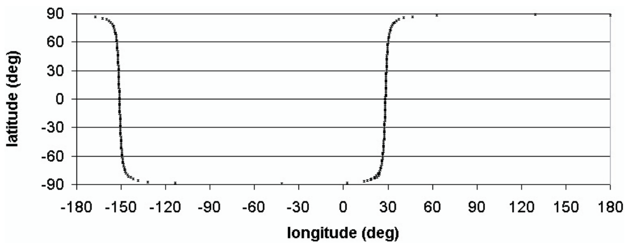

Figure 10. Moon's ground trace in one orbit.

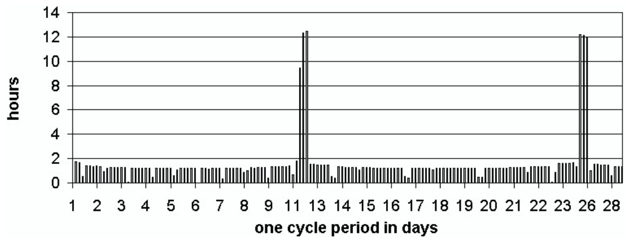

Figure 11. Visible segments of lunar orbit from Bangalore station.

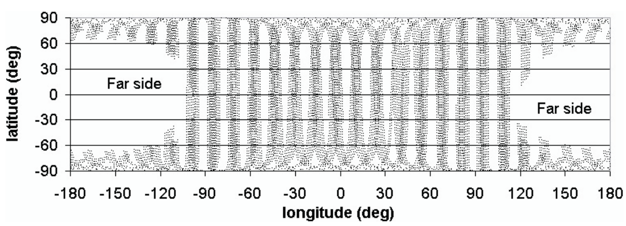

Figure 12. Ground trace during Bangalore visibility.

Imaging camera (Kiran Kumar and Roy Choudhury 2005a) has three channels *viz.*, nadir, aft and fore, each of them generating data at the rate of 12.7 Mbps. Additionally the hyper-spectral imager (HySI) generates the data at 3.8 Mbps (Kiran Kumar and Roy Choudhury 2005a). Thus the full complement of imaging payloads has an input data rate of 41.9 Mbps to the Solid State Recorder (SSR)#1.

Data from SSR#1 is downlinked at the rate of 8.4 Mbps. The SSR#1 is sized for 20 min data input at 50 Mbps and readout/downlink period is 50 min. After recording for 10 minutes in the first file of SSR#1, the data is played back and another file in SSR#1 is opened to store the remaining 10 minutes of data. The operation schedule and imaging strategy considering operational constraints is as follows:

Total contact time	: 70 minutes
Available time for operation	: 60 minutes
Imaging duration	: 20 minutes
Transmission time	: 50 minutes
Simultaneous imaging and transmission	: 10 minutes

The power system has been configured to meet this requirement in the worst case, i.e., imaging the far-side of the Moon even when transmission is done during the eclipse period.

It is clear that when the full complement of payloads is operated, generating 41.9 Mbps, transmission without compression is not possible. It is necessary to employ data compression schemes (both lossy and lossless) to reduce the data volume, thus reducing the time required for transmission. Hence in the allotted 50 minutes of downlink duration, with 8.4 Mbps throughput rate, it is assumed that 1:1.8 lossless compression is used to down-link the full complement of payload data at 41.9 Mbps for 20 minute imaging.

During the *prime imaging zone*, the latitude bands 0° to ±60° are covered. For imaging all these latitude bands, optimal gains and integration times are chosen depending upon the illumination levels of the lunar surface.

Whenever the far-side of the moon is imaged, the imaging data needs to be stored since the lunarcraft is not visible to the DSN. The stored data can be transmitted subsequently when the lunarcraft becomes visible to the Bangalore DSN. The data are collected at 50 Mbps for storage onboard using SSR#1 and later transmitted at 8.4 Mbps to DSN stations. SSR#1 has been sized for an imaging duration of 20 minutes. Imaging strategy takes into account these requirements as well as the DSN visibility to cover the lunar surface. Far-side imaging is the worst case from the point of view of power generation as transmission has to be done during the eclipse period.

The visibility for Bangalore ground station for one cycle is shown in figure 11. Orbit visibility is restricted to a maximum of 12 hours over a day and twice in a cycle of 28 days when the Moon–Earth vector is perpendicular to the orbital plane of Chandrayaan-1. On remaining days, the lunarcraft will be visible for about 70 min per orbit for about 5–6 revolutions out of 12 revolutions.

4.2 *Imaging specifications*

- Providing similar illumination conditions during adjacent orbit tracks.

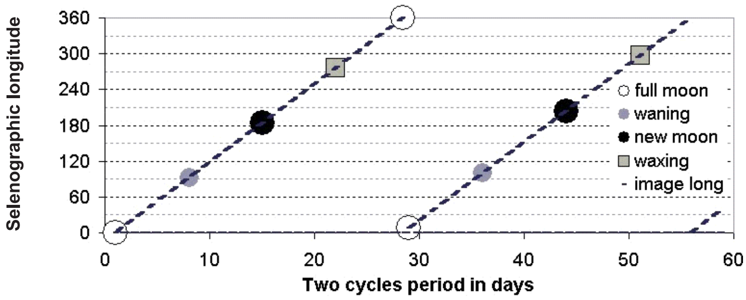

Figure 13. Payload data downlinked to Bangalore station.

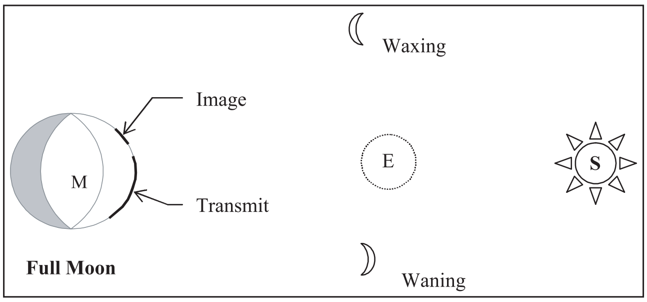

Figure 14. Scheme A (near-side).

- Providing multiple orbit traces for Lunar Laser Ranging Instrument (LLRI) (Kamalakar *et al* 2005, this proceedings).
- Carrying out orbit shift during secondary imaging season, every 15 days when orbit plane is perpendicular to Earth-view, so that the operations and subsequent OD is comfortable.
- Orbit shifts during the next secondary imaging season are to be interspersed between the orbit-tracks already covered (refer figure 16).

4.3 *Moon's longitude coverage*

The Moon's visibility from the Bangalore station ranges around 11.5 hr to 13.5 hr. The lunarcraft orbits the Moon 12 times in a day, of which only 5 to 6 orbits are visible from the Bangalore station.

Figure 12 shows the Moon's surface trace for the period of satellite contact with Bangalore station during the first orbit cycle of 28 days. It is seen that there are gaps in coverage when the station is blind to the satellite. Figure 12 shows that the station is blind in the longitude range of $+120°$ to $-120°$ amounting to one third of the Moon's surface. This is due to the fact that the Moon's revolution period around the Earth is the same as its rotation period, making only one face of the Moon visible to the Earth. Imaging and data transmission can be done only for six orbits on any given day in view of the lunarcraft visibility from the Bangalore DSN. This means that, from the Bangalore station alone, the regions not visible are not imaged during the first cycle. Hence the orbit will be designed such that in the next cycle period of 28 days, the orbit shifts to fill the gaps of the previous cycle so that the entire Moon's surface can be covered longitude-wise in two consecutive cycles. Figure 13 shows the data downloading sequence of the imaged selenographic longitudes to the Bangalore station during two consecutive cycles. It is clearly seen that the gaps left out during the first cycle are swept during the second cycle.

The payload swath is 20 km and the successive orbit track distance is 32 km. Therefore only 50% of longitudinal coverage is possible during one cycle leaving gaps in coverage during successive orbits. The balance 50% is covered during the next season with an induced orbit shift of 16 km.

4.4 *Moon's latitude coverage*

Chandrayaan-1 having a polar orbit, sweeps all the latitudes during each cycle. Due to the constraints in the onboard data handling system, a strip with a maximum duration of 20 min can be imaged which requires 50 minutes of transmission time. Thus, only 60° latitude arc coverage is possible during the first two cycles. During the *prime imaging zone* (when the Sun aspect angle is $\pm 30°$), only latitudes in $\pm 60°$ zone are considered for mapping. However, higher latitude regions above 60° towards both the poles are imaged during polar zonal coverage (when the Sun aspect angle is from $+30°$ to $+45°$ and $-30°$ to $-45°$). During the first *prime imaging season*, only 50% of the latitudes and longitudes are imaged, covering 25% of the Moon's surface. Hence the other three *prime imaging seasons* are needed for total coverage of the entire Moon's surface in the region $\pm 60°$ latitude requiring 20 months.

4.5 *Near-side and far-side imaging schemes*

To cover the entire latitude region of near- and far-sides, two schemes (A and B) are proposed. Scheme A is adopted during near-side (waxing-full

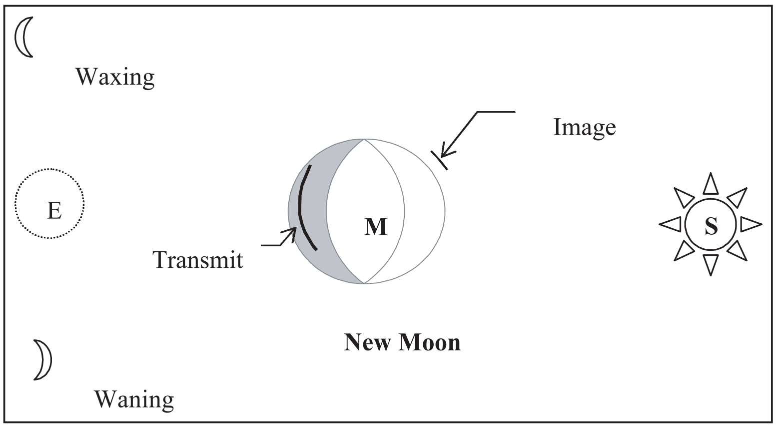

Figure 15. Scheme B (far-side).

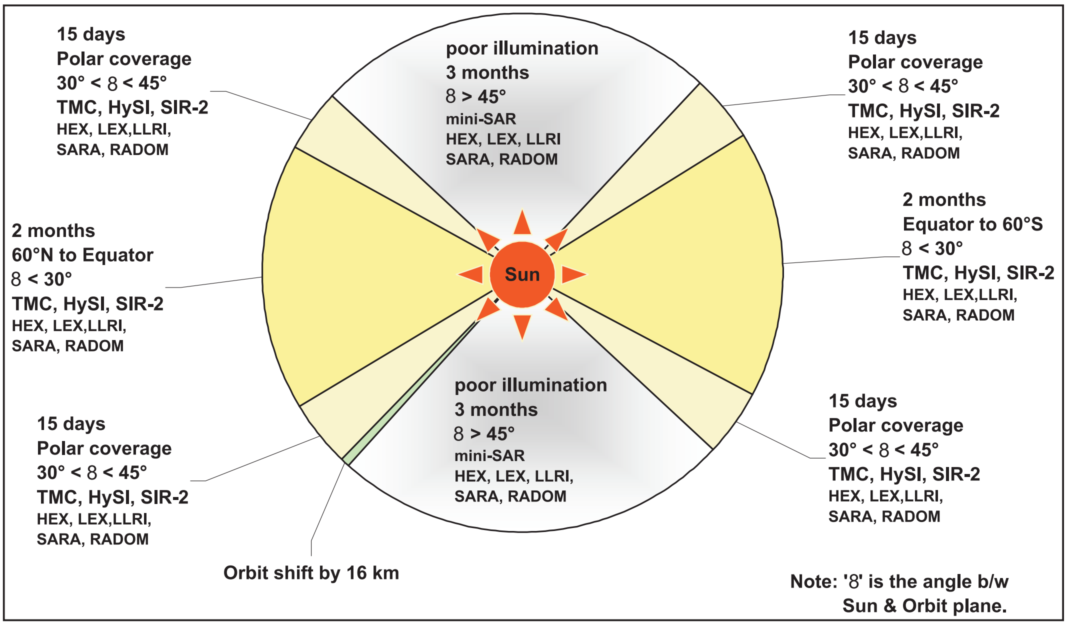

Figure 16. Imaging profile over a year.

Table 4. *Estimated time required for complete lunar surface coverage by Bangalore DSN.*

Area covered in prime imaging zone	60°N to 60°S
Area covered in polar imaging zone	90°N to 60°N, 90°S to 60°S
Latitude zone covered in one visible orbit	60°
Time required to visit all longitudes	2 prime imaging seasons
Time available for each *prime imaging* season	3 months
Time available for each *secondary imaging season*	3 months
Area covered in one *prime imaging season*	25%
Number of *prime imaging seasons*	4
Number of *secondary imaging seasons*	3
Minimum time required to cover entire lunar surface	21 months

moon-waning phase), where the satellite is visible to the ground station while imaging of the sun-lit area. Hence imaging as well as data transmission have to be carried out during the visibility period from the ground station. Figure 14 shows imaging strategy for the near-side.

Scheme B is adopted for the far-side (waning-new moon-waxing phase), when the lunarcraft is visible to the ground station while transmitting during unlit period. Hence imaging is done on the far-side (sun-lit area) and payload transmission occurs on the near-side (non-sun-lit period) that is visible to the ground station. Figure 15 shows imaging strategy while imaging the far-side.

4.6 *Complete lunar surface coverage*

Table 4 provides the total time required for complete imaging of the Moon's surface.

The operations scheduling and imaging strategy can be further improved during the implementation stage with suitable modification of the onboard hardware like SSR#1 size, compression schemes, power availability, increased DSN coverage, etc., to achieve full lunar surface coverage within 21 months.

4.7 *Constraints on payload data collection*

Only DSN at Bangalore is considered for payload data collection. Hence high bit rate payloads like TMC, HySI or miniSAR can be operated in six orbits per day. All other low bit rate payloads are, however, continuously ON and their data are collected by Bangalore DSN.

- The orbit maintenance is done once every 15 days, whenever the orbital plane is face on. During this period, payload operations may be partially affected. The payload operations may be suspended during any orbit manoeuver operations.
- Whenever solar eclipse geometry gets established, the downlink gets affected due to interference and data collection may not be possible. This geometry may last for a day or two.

5. Summary

Details of the analysis to determine the optimal power generation strategy for India's first mission to the Moon, Chandrayaan-1, are presented. In order to meet the primary mission objective of imaging with various payloads, an extensive formulation was evolved considering both the operational and satellite constraints. The salient features of the mission operations and a brief discussion of mission aspects are also presented.

References

Bhandari N 2005 Chandrayaan-1: Science goals; This proceedings.

Bhardwaj Anil *et al* 2005 Low energy neutral atom imaging on the Moon with the SARA instrument aboard Chandrayaan-1 mission; This proceedings.

Goswami J N *et al* 2005 High Energy X-γ ray Spectrometer on the Chandrayaan-1 Mission to the Moon; This proceedings.

Kamalakar J A, Bhaskar K V S, Laxmi Prasad A S, Ranjith R, Lohar K A, Venkateswaran R and Alex T K 2005 Lunar ranging instrument for Chandrayaan-1 (this proceedings).

Kiran Kumar A S and Roy Choudhury A 2005a Hyperspectral imager in visible and near infrared band for lunar compositional mapping; This proceedings.

Kiran Kumar A S and Roy Choudhury A 2005b Terrain mapping camera for Chandrayaan-1; This proceedings.