J. Astrophys. Astr. (2021) 42:21
https://doi.org/10.1007/s12036-021-09731-5

MISSION

AstroSat mission operations management

AMIT KUMAR SINGH*, M. DEEPAN, LEO JACKSON JOHN and B. N. RAMAKRISHNA

ISRO Telemetry Tracking and Command Network, Peenya Industrial Area, Bangalore 560 058, India.
*Corresponding author. E-mail: amit@istrac.gov.in

MS received 4 November 2020; accepted 11 February 2021

Abstract. AstroSat is India's first dedicated astronomical observatory in space with multi-wavelength payload on a single platform. It enables simultaneous observations in the desired wavebands. The increase in the number of payloads has also led to an increase in the complexity in space segment design, ground segment design, and mission operation management. Each payload instrument and mainframe has its own constraint for the operation, which needs to be satisfied to ensure the safety of the systems. In this paper, we explain the challenges in ground operations for mission management with various constraints. Also, we list the various constraints, both geometric and otherwise, with respect to the mainframe systems and payload instruments of AstroSat.

Keywords. AstroSat—mission operation—on-board constraint.

1. Introduction

To study the cosmic sources, satellite-based space observatories provide us a better vantage point than ground-based observatories. This is because measurements made by space-based observatories are free from errors arising due to atmospheric effects. Since the intensity of most cosmic sources varies with time, the variability being wavelength-dependent, it is necessary to make simultaneous observations in different wavebands. However, there are several logistical problems in making simultaneous and coordinated studies of a specific object from different satellites and ground-based telescopes. As a result, despite many such multi-wavelength observation campaigns, very few sources have so far been studied over wide spectral bands leading to poor understanding of the underlying physical processes. With these problems in mind, a dedicated satellite called AstroSat was designed with multiple co-aligned instruments covering the desired spectral bands so that simultaneous observation in all the desired wavebands is possible.

AstroSat is designed and developed with five astronomy payloads (UVIT, LAXPC, SXT, CZT, SSM) covering optical, Near-Ultraviolet (UV), Far-UV, and X-ray frequency bands and was launched on 28th September 2015 by PSLV-C30 (XL) from Sriharikota, India. The spacecraft was put into a 650 km near-equatorial orbit with an inclination of 6 degree to meet mission objectives.

2. Mission operations and planning

AstroSat is an inertially pointed satellite with the instrument view axis oriented towards the celestial source for observations in multi-wavelength. The AstroSat payloads are designed to sense the faint signal from the distant objects and are capable of identifying the signal source at arc-second angular separation. Conforming to the above requirement resulted in design of payload system which are very sensitive to the signal intensity, attitude deviation and jitters on the platform. This requirement imposes the constraint on on-board control system and mission operation management.

This article is part of the Special Issue on "AstroSat: Five Years in Orbit".

Published online: 28 May 2021

Different payloads of AstroSat, operates in different frequency bands and each payload has its own operating constraint. To ensure the safety of on-board instruments, it is of utmost importance to verify that the commands, that are up-linked to the satellite conform to the constraints of all the payloads and mainframe sub-system.

The validation of the geometric constraints for payload operation starts from the proposal submission on-wards till the generation of final command list, at different levels by different software with different time period and accuracy level. The mainframe subsystem constraint is validated by operations team before uploading of commands to the satellite.

The AstroSat payload operation is based on a proposal driven system. The proposal submission starts six months in advance with Announcement of Opportunity for users. The users first check the feasibility of their intended source using the Astroviewer portal, which check the observation feasibility for a duration of up to one year over specified start and end time. After the feasibility check with respect to geometrical constraint, the proposal is submitted for observation through the AstroSat Proposal Processing System (APPS). The Submitted proposal is validated for science merit by AstroSat Time Allocation committee (ATAC), based on recommendations on technical feasibility by the AstroSat Technical Committee (ATC). The final list of the proposal for next six months/one year is stored into a Mission Control and Proposals (MCAP) database for further processing.

The next level of scheduling of proposal happens for fifteen days in sliding window pattern. This task is executed by the AstroSat Scheduler Software for operations (ASSORT) with latest orbit parameter and geometric constraints validated with finer accuracy. A Payload Operation Plan scheduler uses the aforementioned files and generates time lined command sequence outputs for a pre-planned observation. The scheduler creates an observation sequence plan with constraints check using orbit related events such as eclipse, South Atlantic Anomaly (SAA) entry/exit, Earth occult entry/exit, X-Band data dump feasibility, station visibility, star sensor availability, earth limb brightness viewing etc.. The corresponding commands are generated and posted in the operation area for uplink.

The operations team runs the final validation (Mamidi *et al.* 2020) for payload and mainframe constraint check before uplinking of the command. The constraint validated by the operation team is explained in detail in next section. When observation is in progress, the two critical constraints namely Inertial sensor drift and separation angle between the Sun and spacecraft payload axis are monitored at each orbit interval to meet the mission specifications. Corrections are carried out from ground whenever the observations deviate from the desired limits.

3. Constraints in mission operations

The AstroSat is a three axis stabilized spacecraft. the axis definition of Astrosat is shown in the Fig. 1.

The proposal which are selected for the observation are validated for conformance to the following geometrical constraints:

(1) Payload axis should never see the bright object in their respective operational wavelength (visible, near UV, Far UV) during operating condition.
(2) Payload axis and the Sun vector angle should not be less than 65 degrees.
(3) Payload axis and Velocity vector angle should not be less than 12 degrees.
(4) Cross axis-1 should avoid sun by 100 degrees.
(5) Cross axis-2 should maintain 90+/–0.5 degrees with Sun.

The celestial sources which satisfy the above constraints are selected for observation for corresponding payload planning cycle.

Since, the attitude of the observatory is held fixed in inertial space throughout the observation, it causes payload axis and attitude sensor bore sight axis to observe the Earth every orbit. The average blockage duration by the earth per orbit varies based on the location of the celestial source in inertial space. The source located near equatorial plane cause the maximum blockage duration of approximately 35 minute per orbit. The sources with declination of greater then 66 degrees will not face payload axis blockage by the Earth. The X-ray payloads are safe during earth occult duration even though they do not observe the source, while the optical payload is sensitive to scattering due to Earth"s albedo and needs to be put OFF whenever payload axis to Earth albedo angle goes below 12 degrees.

AstroSat has two star trackers for attitude measurement mounted with sufficient separation angle to ensure attitude measurement from at least one sensor during observations. The field-of-view of the Star trackers need to be away from Sun, Moon and Earth albedo by certain angles to provide measurement. Hence while planning orientation for any source, the

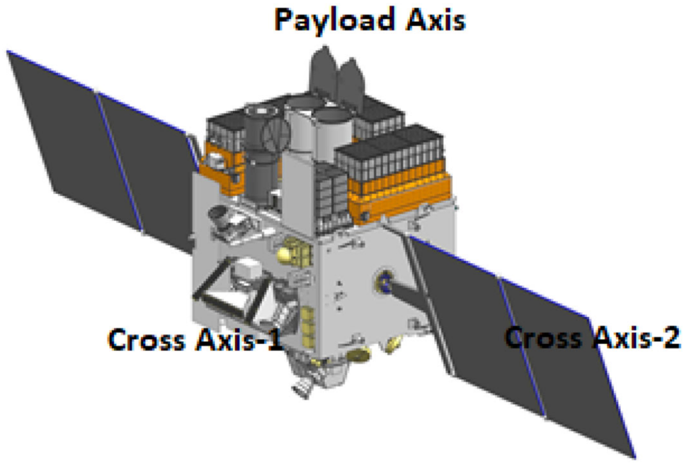

Figure 1. AstroSat axis definition.

Star tracker availability needs to be predicted in advance and necessary actions to be taken on ground accordingly.

The part of the orbit when star trackers are occulted, inertial sensors (gyros) control the platform. Gyros are having inherent drift, which needs to be estimated on ground, based on post facto attitude analysis and corrected periodically to meet the pointing requirement of the payload. Since the AstroSat attitude is inertially held throughout the observation period, it becomes necessary to validate the number of stars available in FoV of star tracker for each observation. Only those sources are planned for observation for which at least one star tracker is available.

Most of the AstroSat payloads are operated at high voltages during observation time. The X-ray payloads are prone to failure when the spacecraft passes through the South Atlantic Anomaly (SAA) region, where charged particles are also detected, leading to very high count rate which can lead to high voltage breakdown. AstroSat crosses the SAA region every orbit. In order to safeguard the systems from high energy particles, payloads are operated with low voltage configuration during SAA region and those data are not used for scientific purpose.

The UVIT payload is very sensitive to light intensity, which puts operating constraint during the sunlit part of the orbit. To conform to this requirement, UVIT payload is always planned in eclipse, non-SAA region and Earth occult free zone.

All payload instruments are continuously ON storing the data in on-board memory. On-board has the memory capacity of 144 Gb. The expected data to be recorded per orbit is around 40 Gb. The recorded data is downloaded every orbit over dedicated ground station situated in Bangalore. As per the data volume generated per orbit and on-board memory storage capacity, the data download opportunity exist for nearly 3 orbits. These payload data are very precious and unique especially in case of Astro Events and is of high importance. Since these data cannot be recreated unlike in IRS satellite, where multiple opportunities exist to capture the same area. therefore, to avoid the overwriting of useful data, the quality of downloaded data needs to be checked for every download orbit. In case the data quality is below acceptable threshold, re-dump needs to be planned within certain time periods. The re-dump operation is highly unpredictable and to be performed by the operations team based on real-time observation.

AstroSat has two-phased array antennas providing omni-coverage for X-band data download. One of the antenna provides a clear FoV and there is partial blockage for the second one by on-board appendages. The blockages are predicted on ground *a priori* and mitigation plan is executed by the operations team to ensure error free data download.

4. Mission operation challenges and management

The AstroSat provides a platform for the user community to perform simultaneous observation of the celestial source in multi-wavelength band. This system was realized by increase in the number of on-board payloads, which has also led to an increase in the complexity in space segment, ground segment and mission operation. Each payload instrument and mainframe has their own constraint for the operation, which need to be satisfied to ensure the safety of the systems.

The AstroSat payload operation related commands are uploaded on-board one day in advance, after the validation of all the constraints at different level. There are certain critical operations which need to be performed by operation team in the real-time pass during the observation period. These operations depend on the response of payload instrument and mainframe system for that observation source and corresponding attitude. The requirement and frequency of these operations is decided by the post facto analysis. In the following sections, the operation scenario and challenges are discussed in further detail.

4.1 *On-board programming constraint*

Though AstroSat payload planning is done 15 days in advance by the scheduler, the final command sequences cannot be uploaded at once due to multiple operational limitations. The payload operation includes On-Board Time Tag (OBT) based commands related to various events such as enabling/disabling of Star tracker updates, SAA Entry/Exit, Data download, X-Band On/Off, attitude maneuver sequence commands, Solar panel Offset, UVIT On/Off and other configuration commands. The maximum number of such OBT events which can be stored on-board is limited to 512. Since the average number of required events uploaded to spacecraft over a day is around 250, this calls for daily upload of commands and cannot be programmed for more than 2 days, definitely not weeks in advance. Apart from planned observations, there is provision to submit Target of Opportunity (ToO), with short notice. This also puts limitation for long term on-board programming.

4.2 *On-board timer drift*

Since, the AstroSat observation are very time critical and on-board operation depends on OBT timer. It becomes necessary to maintain the drift of the on-board timer within mission specification, which calls for frequent OBT drift estimation and correction from ground. Since the drift is directly related to the temperature of the on-board clock generator, the frequency of this operation varies based on the source orientation.

4.3 *Long-term observation planning constraint*

In AstroSat, the source pointing attitude is derived based on the Sun position at start of the observation. Subsequently, all the geometric constraints are validated against this attitude and AstroSat is inertial pointing to the defined attitude during full observation period. Since, AstroSat has stringent constraint limit of +/–0.5 degree variation for the cross axis-2 with respect to the Sun, and the apparent motion of the Sun is 0.9856 per day, the observations which are planned for long duration, i.e. more than two days puts overhead on ground operations. Hence frequent attitude corrections maneuver are needed to compensate the apparent Sun motion. This operation is done for observation duration exceeding 130 kilo-seconds and corrections are to be performed when no other sequencer or UVIT operation or payload data dump is in progress.

4.4 *Gyro drift correction*

Attitude pointing requirement for the UVIT payload is very stringent and any deviation may lead to switching OFF of the instrument by on-board safety logic. The gyro drives the platform in absence of Star tracker update and is prone to drift causing attitude deviation. During such periods, the drift is estimated at the ground and correction commands uploaded. This is a regular operation in AstroSat and frequency of operation varies depending on the orientation in inertial space.

4.5 *Payload reset operation*

To meet the requirement of periodical UVIT instrument reset which are time critical, ground planning needs to be done to ensure that no UVIT related events are programmed during this operation. Also, critical monitoring is required after every such reset to assess the instrument status and take appropriate actions for any deviations.

4.6 *Critical health monitoring*

AstroSat has stringent real-time health monitoring requirement for mainframe and payload systems. In every orbit due to SAA crossing, the payload instruments transit from high voltage to low voltage and vice versa and these transition events are pre-programmed from ground. Quick action needs to be taken from ground during the limited contact time with the satellite (maximum of around 15 minutes) in case of any abnormal behavior. The assessment of proper functioning of mainframe systems to satisfy the mission specification during real-time pass and take corrective action for further operation is very time critical task, mainly the attitude control and power systems. This is the herculean task to be performed by operation team in real-time pass. To reduce the real-time health monitoring load, OOL (Out Of Limit) based anomaly detection software is deployed in operational environment. The expected limit of the parameter has been configured based on the on-board system performance during the initial phase of the mission. This software has played the significant role in safeguarding the satellite.

4.7 *Operation management during lunar shadow*

The maximum load on the bus is around 1.6 kW and maximum solar power generated is around 2 kW. In case of lunar shadow which occurs few times in a year, the power generation reduces and appropriate load shedding operation is planned and executed from ground to maintain positive power margin.

4.8 *Operational overhead*

As explained in earlier sections, the final planning of the payload operation and corresponding commands sequence are uploaded to on-board, one day in advance. As per the mission definition and selected orbit requirement, no orbit raising maneuver is required throughout the mission life of AstroSat. But to safeguard the satellite from debris, collision avoidance maneuver (Singh *et al.* 2014) is to be planned as per the requirement.

The collision avoidance maneuver warning comes to the operation team in 12-hour window and which is mandatory operation. In view of the collision alert, orbit maneuver operation needs to be planned and executed within 3 orbits, which involves:

(1) Finding the suitable time for maneuver for the ongoing source with respect to thrust axis to velocity vector angle. In case if angle is not favourable for the maneuver, planning of new source to satisfy the maneuver requirement through Sun Avoidance Maneuver (SAM).
(2) Planning of the orbit maneuver and creating corresponding command sequence.
(3) Disabling of all the planned operation in on-board memory which are clashing with new maneuver time.
(4) Execution of the collision avoidance maneuver operation as per the plan provided by the Flight Dynamics team.
(5) Normalization of the routine operation.

This operation disrupts the full chain of the routine sequence, which needs to be restored after the execution of the maneuver operation. Till date, one collision avoidance maneuver is executed for the AstroSat mission.

4.9 *Anomaly and contingency handling*

The operation team is responsible for health monitoring of the spacecraft and detection of any deviation in on-board system. The OOL based real-time health monitoring softwares are deployed in operation area to detect any deviation from the expected range. If any anomaly alarm is observed during the real-time pass, the spacecraft controller will validate the alarm, initiate preliminary action to safeguard the spacecraft and alert the concerned team for further actions and normalisation. This operation involves coordinated effort of the sub-system designer, mission team and operation team. As part of post recovery operation, based on the implication of the anomaly, on-board configuration and operation strategy are modified to avoid future occurrence of same class of anomaly.

5. Software developed for operation management

AstroSat operation is unique in nature and different from other on-orbit satellites. The management of such complex and dynamic mission operation scenario with manual decision making is a Herculean task for the operation team. To handle all these monitoring and operational requirement various software modules are developed by the operations team and implemented for regular operations.

The utilities developed facilitate the operation team with an independent system to perform following operations:

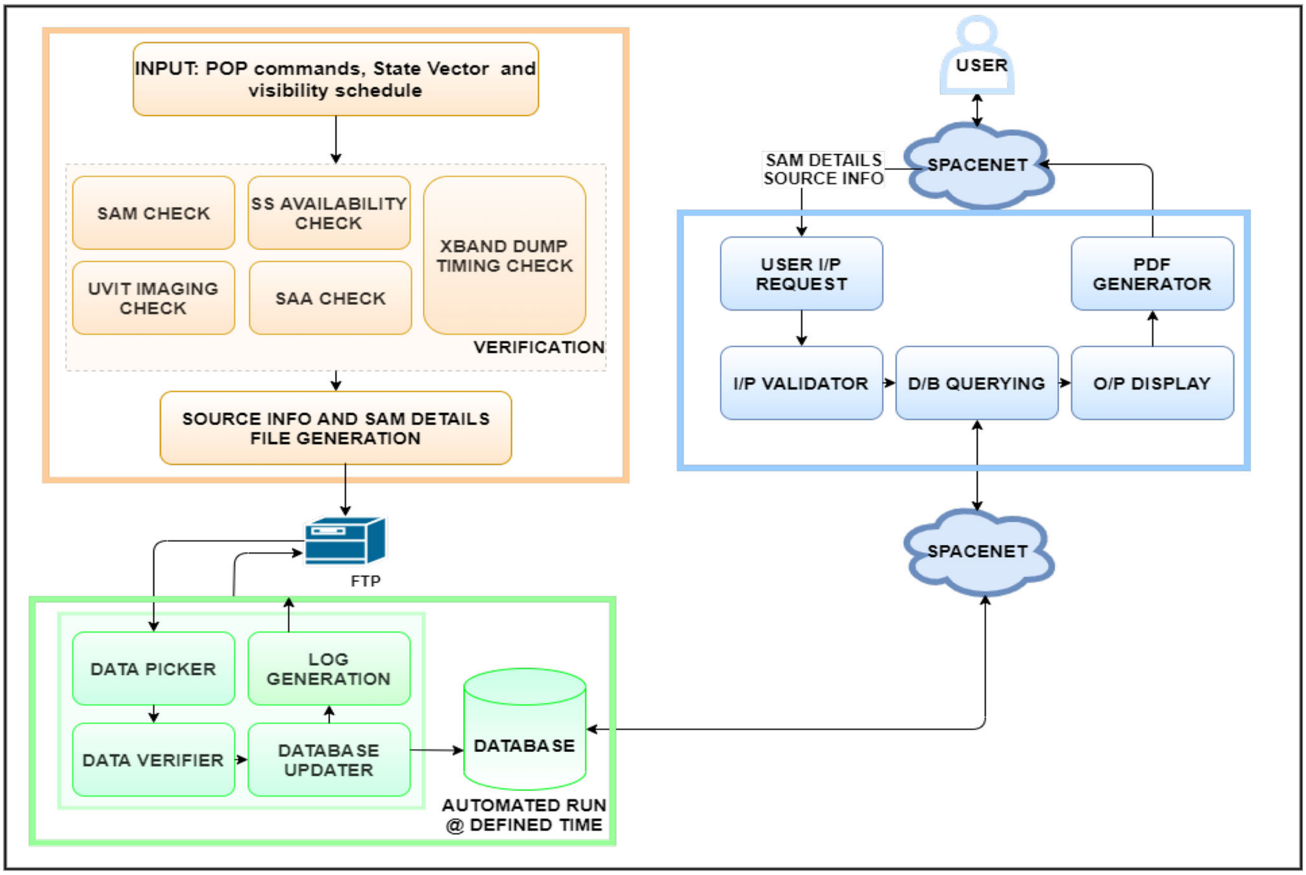

Figure 2. AstroSat operations portal data flow diagram.

(1) Validate (Mamidi *et al.* 2020) the planned operation with respect to the defined mission constraint.
(2) Generates the visual display of the planned operation timeline.
(3) Keeps track of up-link events and validate the execution of operation at desired time through telemetry data.
(4) Checking re-dump requirement and generates command for the same.
(5) Estimate the inertial sensor drift and generates the correction command using offline telemetry data and in-build algorithm.
(6) Prediction of attitude maneuver requirement and time of correction operation for each planned observation.
(7) Maintains the database of daily payload operation and on-board events.
(8) Provides the user interface to access the payload statistics through intranet.

This data is made available to the operations team in graphical form and tabular form like event clash, regime of operation planned, efficiency of the payload operation carried out, duration of the payload and regions covered. Figure 2 represents the overall data flow of the operations portal.

The three core modules of operations portal are as follows:

(1) The validation and verification of payload based on the constraints as discussed earlier are carried out by a software module. All the events are represented by the different colored bars. the overlapping of the events can be visually verified with ease by the spacecraft controller in addition to automated constraints verification.
(2) The validated and verified information about payloads are then collected and transferred through FTP to the server network. This collection of information happens periodically at defined time and the database is updated after verification.
(3) The database is accessed through a web interface internal for ISRO users for report generation and analysis.

6. Conclusion

This paper was brought out to emphasize the challenges involved in the mission operation management. In spite of various constraints and limitations, operating the spacecraft as per the plan has been achieved with an aim to provide maximum science data to the users.

Acknowledgements

We would also like to extend our appreciation to ISTRAC operations team including spacecraft controller, ground station operation teams, ISSDC team for their sincere effort in managing the operations in 24 × 7 time line. We would be remiss to not mention the substantial support received from mission team of U. R. Rao Satellite Center, other ISRO centers and payload instrument teams.

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