Turning Off the Lights: Automating SkySat Mission Operations

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ABSTRACT

A common goal for satellite operations is to achieve a level of automation that minimizes human interaction, especially as constellation sizes increase. Planet's SkySat fleet is a constellation of high resolution Earth imaging smallsats that has grown from three to fifteen satellites in three years. This rapid expansion, along with Planet's goal of improving operational reliability, has necessitated automating operations to reduce manual effort to maintain the health and safety fleet. To address the growing amount of work required for anomaly triage, systems were created for automated anomaly response. These systems have removed the need to actively monitor satellite health and safety. Instead, operators rely on interrupt-driven alerts to inform them of an anomaly. With the goal of further decoupling fleet size from operator effort, the mission operations team is working to automate routine maintenance tasks. As a result, the number of person-hours needed to actively operate the fleet has seen a three-fold reduction per week while enabling a five-fold increase in on-orbit assets. The systems developed have enabled an operational posture that removes the need for 24/7 staffing at a dedicated operations center.

INTRODUCTION

Founded in 2010 by a team of ex-NASA scientists, Planet is an earth observation company providing mid- and high-resolution imagery taken by a constellation of satellites in low Earth orbit. Planet is currently operating 140 satellites including five RapidEyes, a flock of 120 Doves, and a fleet of fifteen SkySats. With this heterogeneous constellation, Planet captures imagery of almost all of the Earth's land mass on a daily basis. The focus on automating mission control and operations has continued to enable Planet's mission as the constellation scales.

The SkySat Fleet

The SkySat fleet is comprised of fifteen small satellites capable of sub-meter resolution imagery. Unlike the Dove flock, which provides near-continuous imagery along each satellite's orbit, the SkySats capture on-demand imagery of targets requested by customers. In addition, while the Doves are 3U CubeSats numbering in the hundreds, the SkySat fleet consists of a few dozen small satellites in the 100 kg range. The SkySat fleet is comprised of satellite buses with both maneuverable and non-maneuverable capabilities. Apart from this difference, the various SkySat buses are largely the same and operate under the same concept of operations.

The rapidly changing operational needs required to maintain the fleet dictated that the SkySat Mission Operations (SMO) team develop tooling around the ground software, described below. These tools would give the team greater control over features while staying as independent as possible from the deployment of new ground software releases. By decoupling this development, SMO could experiment with various automation strategies while maintaining the inherently stable ground software. The ultimate goal of automation was to minimize the effort required to operate the fleet and maximize the amount of time operators could be absent from the operations center, in a so-called lights-out operational posture.

GROUND SOFTWARE AND TOOLING

The base ground system initially provided to operate the SkySat fleet was a web-based user interface with basic features such as scripted command execution and telemetry monitoring and charting. As the number of satellites in orbit grew and operational needs changed, this base infrastructure acted as the foundation for additional tools built to facilitate SkySat mission operations.

Scripting Engine

One of the primary features of the ground system allows operators to execute prepared scripts, written in Python. The purpose of this feature was to improve upon on-orbit command execution by allowing for complex logic and telemetry verification. The use of scripts has significantly reduced the occurrence of operator error and as a result increased fleet uptime.

The first scripts developed were simple wrappers for available command and single-point telemetry checks. In these scripts, operators still adjusted the logical flow of execution via command line prompts. Over time layers were added to the script library, logic became more complex, and the need for operator prompting diminished. Much of this was due to the cumulative experience of both operators and engineers in dealing with anomalies on-orbit.

Telemetry Monitoring and Charting

Operators are able to create custom screens of telemetry points for monitoring specific aspects of the satellite, as well as chart, in real-time, downlinked telemetry data from the satellite. Historical data is kept in a database to be retrieved for long-term trending of satellite data.

Additionally, the ground system continuously monitors incoming telemetry against a set of thresholds defined by the satellite engineering team. These violations are then recorded and a visual indicator is presented to the operator for further action.

Organization and Planning Tools

In order to facilitate executing satellite activities, SMO developed the pass planning tool. With this tool, operators may plan and display which operator-initiated activities would be executed in future contacts for each satellite. Additionally, this tool gathers and displays information about the fleet including what activities a satellite will be performing in upcoming orbits, the location of the satellites, and the health and safety effects of upcoming activities. This organization and planning tool became the foundation for many of the future tools that SMO would build, as it evolved into a one-stop location for all of the data the operations team needed.

PROCEDURAL AND TASKING ALGORITHMS

As the fleet expanded, a multi-prong approach was taken to decouple operator effort from fleet size. This included building upon existing script libraries for automated anomaly response, moving to an alert-driven operational posture, and reducing the burden of planning and executing maintenance activities.

Automated Anomaly Response

Over time, a set of common anomalies has emerged across the fleet that has lead to a thorough understanding of how to triage and resolve said anomalies. These well-defined responses to known anomalies have been implemented into scripts, which can be executed any time an anomalous state is detected. This development eliminated the need for operators to monitor real-time telemetry in order to respond to on-orbit issues.

Autonomous anomaly response is an integral part of SkySat operations. Responses to common anomalies are entrusted to automation instead of operator intervention. By laying the foundation of autonomous anomaly response, the operations team was able to transition from focusing attention on one satellite at a time to considering and investigating anomalies at a fleet-wide scale. This enabled the operations team to more effectively manage a growing fleet. By automating the most critical responses, human attention could be more evenly spread between satellites competing for resources.

Back-orbit Activities

A majority of commanding for all satellites in the SkySat fleet is done procedurally via a timestamped sequence of commands. These sequences are prepared and validated on the ground prior to being loaded to the onboard software for execution. These activities, such as image captures, data downlinks, and maintenance tasks, are typically performed in this manner.

Some maintenance activities with specific constraints, such as onboard storage cleanup, must be executed when the satellite is not in contact with a ground station. To execute these “back-orbit” activities, a suitable execution time must be found and the sequence of commands must be loaded to onboard software prior to that time. Traditionally these tasks were manually performed by operators, which required a thorough understanding of not only when the satellites would be collecting images, but also the orbital state and satellite attitude. For example, would the satellite be passing through the South Atlantic Anomaly (SAA) and will the satellite be in an unsafe orientation if the activity is performed? Automating this process required defining a clear set of constraints that could then be implemented into the logic for determining the appropriate time to execute an activity. Once a suitable window was generated, the sequence of commands could then be embedded into the upcoming activities performed by the satellite.

Table 1 shows a simplified representation of the possible timing of a task that must be done while the satellite is in eclipse, not in the SAA, and not interfering with images or contacts. The final row indicates that there are two blocks near the end of the eclipse period that meet these criteria. If the length of these blocks is sufficient to complete the task, it will be added to the sequence of commands loaded to the satellite for that time frame.

Table 1: Back-orbit Activity Scheduling

Eclipse												
SAA												
Imagery												
Contact												
Taskable	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗

Alert and Paging System

One of the greatest enablers of lights-out operations was the development of an alert and paging system. If an anomaly occurs on orbit or within the ground infrastructure, the alerting system generates a summary of information surrounding the event to inform the on-call operator of the incident. Tying the alerts into Planet’s existing ticketing system meant issues could be tracked from discovery to resolution.

Historically, visual indicators signifying that the value of a specific telemetry point was outside a defined threshold were used by operators to identify an anomalous scenario on-orbit. These, alongside logged messages from the onboard computer, were used by operators to triage and respond to the anomaly. At the core of its design, the alerting system collates related messages and telemetry into a single notification to send to operators.

The precision and completeness of this information allows operators to develop a plan of action without requiring the depth of investigation needed in the past. Combined with changes to the operational posture, specifically extending the time in which operators must respond to an anomaly, this information enabled operators to work outside the operations center and respond to anomalies when convenient.

AUTOMATED OPERATOR

After implementing automated scheduling of back-orbit activities, the last thing operators were responsible for was the planning and execution of activities that required communication with a ground station. These activities require ground services for a number of reasons, such as needing a link for telemetry verification or data exchange. These “in-pass” activities are frequently used for anomaly investigation and resolution, software updates, and nominal maintenance. In order to further reduce the person-hours needed to manually plan these activities, the SkySat Mission Operations team needed an automated workflow to determine what activities needed to be executed. In addition, this workflow needed to schedule the activities and to verify their successful completion.

With the introduction of a so-called “automated operator”, all non-anomaly planning and scheduling could be handled without operator intervention. Tasks in this system were separated into three categories: default plans, run when no other activity is required;

recurring plans, maintenance activities run at a regular interval; and triggered plans, activities that are planned in response to on-orbit conditions. The core functionality of the automated operator is scheduling these activities and verifying their successful execution.

Default Plans

A majority of contacts across the fleet perform nothing beyond routine satellite health and safety checks. These routine tasks are encapsulated in a single script, removing the need for real-time telemetry verification by operators.

Before the implementation of the automated operator, the "default script" was scheduled via a temporary workaround added to the pass planning tool. This occasionally led to scheduling conflicts and activities that had been carefully planned by operators could be overwritten without notice. This was an acceptable occurrence when the fleet was smaller, since the time it would take for operators to investigate why an activity did not occur did not interrupt nominal fleet operations. As the fleet grew, it became apparent that the system needed a new way to schedule these default tasks. By centralizing all contact scheduling into the automated operator, there was no longer a requirement for operators to manually ensure that a planned task would not be overwritten.

In order to not interfere with operators manually planning a contact, the automated operator will only schedule recurring or triggered plans if a default plan was there previously. Human operators still have the authority to schedule and execute activities independently of the automated operator.

Recurring Plans

There are certain tasks that must be executed at defined intervals as prescribed by the responsible subsystem engineer. Many of these tasks require ground assets and cannot be done while the satellites are not in contact. Some of these include loading updated orbit information or loading software configurations to the satellite. The intervals at which these tasks are executed range from weekly to quarterly.

The automated operator is responsible for all aspects of these activities, including the following:

- Tracking the status of all individual activities to determine if a task needs to be scheduled (activity scheduled; activity failed; activity recently completed successfully)
- Tracking constraints for scheduling (minimum contact duration; ground station exclusions)
- Tracking templates for activities approved for automated scheduling

Triggered Plans

There are certain on-orbit states that are typically dealt with in a well-defined manner. These activities are necessary for performing on-orbit tasks such as routine cleanup of satellite storage and enabling certain subsystem configurations. By defining both the on-orbit state and the necessary response to that state in a script, the automated operator schedules these activities as needed without operator intervention. As with default and recurring plans, these triggered plans are monitored from schedule planning through execution verification by the automated operator.

PERSONNEL AND STAFFING

Despite the fleet size growing from one to fifteen satellites, staffing has remained relatively constant. This is due to evolving operational postures as well as the growing role that automation has played.

Traditional Operations

Historically, satellite operations has involved staffing a dedicated operations center 24 hours a day, seven days a week. With the launch of SkySat-1, this was the posture taken, with three operators on console monitoring satellite health and safety. This was then reduced to two personnel when commissioning was complete. Outside of commissioning activities, 24/7 two-person operations (2PO) was maintained until 2017.

Lights Out and On-call

The transition to on-call operations started with allowing the nighttime operators to monitor the fleet remotely, relying on the paging system to alert of any anomalies that needed operator response. This was referred to as nighttime lights-out operations (NLO). As confidence in the systems grew, nighttime staffing was reduced to one person on-call, with another support engineer available to be contacted as needed. This 24/7, one person on-call stance was eventually extended to include weekends in what is referred to as weekend lights-out operations (WLO). After on-call operations was implemented, operators were in the operations center twelve hours a day on weekdays with the remaining hours covered by on-call personnel.

The team operated with these twelve-hour on-call shifts until in-office hours were eventually reduced to follow a standard eight-hour workday. Operators who began their shift on a weekday morning would finish their shifts remotely for a total of twelve hours on-shift. Operators assigned to weekend shift conducted shift activities, such as anomaly resolution, remotely.

Alerting Periods

Despite moving to an on-call, interrupt driven stance, the SkySat Mission Operations team was still faced with the burden of having operators on-call 24/7 to respond to satellite anomalies. As the systems in place matured, the operations team relied on automation to take over more of the responsibilities of responding to night and weekend anomalies. With a growing number of the fleet, overall performance would not be greatly impacted by downtime on a few satellites.

After the initial deployment of the alert and paging systems, there was a period of time where operators closely scrutinized and double checked that anomalies were being caught as expected. As confidence in the automation among operators reached a sufficiently high level, a change in operational stance was made to allow automation to be the primary response at night. Engineers could then triage anomalies in the morning and take action as necessary. This was the first time where there was a period of the day when no personnel were actively monitoring the fleet. This so-called "muting period" was then extended to 16 hours, turning the on-call period into an extension of in-office hours as opposed to staffing a separate shift.

As it currently stands, the nighttime on-call period has been completely eliminated, with operators in-office only for a normal workweek and on-call personnel available during the day on weekends. Introducing the automated operator has further reduced human operator effort by covering all routine maintenance tasks. Although on-console for a full day, a typical day sees operators performing on-orbit activities such as anomaly response only a few hours per day.

The overall reduction in staffing hours to monitor the fleet has reduced from 336 person-hours per week to 96 person-hours per week, with on-console operators spending less than half of their shift fully devoting attention to the fleet. This reduction in staffing occurred in parallel with fully supporting fleet expansion from one to 15 satellites. As stated previously, staffing levels have remained relatively constant. With the reduction in effort required to maintain the fleet, the mission operations team has provided support to other subsystems of the SkySat platform, including flight software, ground software, and manufacturing. The SkySat Mission Operations team has evolved into a group of subject matter experts on many aspects of the SkySat platform. This cross-training has made the level of knowledge related to the SkySat fleet at Planet resilient to changes in the overall team composition. Many members of the team have transitioned to other teams at Planet, specializing in disciplines ranging from electrical engineering to project management. Without the continued improvement in automation and relaxation of the operational posture, these changes would not have been possible.

Table 2: Weekly Staffing Plan (in FTEs)

<table>
<tr><th rowspan="2"></th><th colspan="4">WEEKDAYS</th><th colspan="4">WEEKENDS</th><th>TOTAL</th></tr>
<tr><th colspan="2">Day</th><th colspan="2">Night</th><th colspan="2">Day</th><th colspan="2">Night</th><th>hours</th></tr>
<tr><td>2PO</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td>336</td></tr>
<tr><td>NLO</td><td colspan="2">2</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">1</td><td>252</td></tr>
<tr><td>WLO</td><td colspan="2">2</td><td colspan="2">1</td><td colspan="2">1</td><td colspan="2">1</td><td>228</td></tr>
<tr><td></td><td colspan="8">TRANSITION TO MUTING PERIOD</td><td></td></tr>
<tr><td>8hr</td><td>2</td><td colspan="2">1</td><td>0</td><td>1</td><td colspan="2">1</td><td>0</td><td>152</td></tr>
<tr><td>12hr</td><td>2</td><td>1</td><td colspan="2">0</td><td colspan="2">1</td><td colspan="2">0</td><td>124</td></tr>
<tr><td>16hr</td><td>2</td><td colspan="3">0</td><td>1</td><td colspan="3">0</td><td>96</td></tr>
</table>

CONCLUSION

In six years, the SkySat Mission Operations team has gone from operating one to fifteen satellites, with a further fleet expansion on the horizon. This has been accomplished while not only maintaining a constant and lean team size, but while also scaling imaging capabilities to full capacity and maintaining rigorous mission uptime requirements. The introduction of the automated operator freed human operators of the burden of routine maintenance tasks, only requiring intervention during anomalous scenarios. The key factor of the team's success was reducing the amount of work operators needed to perform per satellite, shifting the perspective from one of maintaining individual satellites to one of maintaining a fleet. This shift represented an understanding that imagery products were resilient to temporary outages on satellites.

Lessons Learned

Automation is not something that happens all at once. Since the launch of SkySat-1, the mission operations team has incrementally developed systems and processes to assist in the routine maintenance of the growing fleet. Had automation been designed into the system upfront, the operational cadence and risk posture would have been rigid and unresponsive to the ever-evolving needs of the mission. Instead of dictating the automation needs of the operations team, the ground software systems are flexible, centering around a scripting engine and application interface.

Even if a piece of automation is designed and works perfectly, time is still required after the initial deployment for the full benefit to be realized. Before operators fully unburden themselves of the task to be automated, there will be a period of time where operators double check and question the efficacy of the automation. It is important for the software team responsible for deploying new automation tactics to understand and work with the operators. In other words, winning the hearts and minds of the operators is key to successfully automating an operations environment.

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References

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