# Current Level of Mission Control Automation at NASA Goddard Space Flight Center

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**Abstract** 

NASA is particularly concerned with reducing mission operations costs through increased automation. Specifically, NASA has been studying the use of Artificial Intelligence (AI) to further automate mission ground operations. This paper examines the operations procedures within NASA Mission Control Centers in order to uncover the level of automation that currently exists to determine whether it is necessary and cost effective to implement AI technology within them. Based on an assessment of mission operations procedures within three representative control centers, this paper recommends specific areas where there is potential for mission cost reduction through the application of AI and other automation technology.

## Introduction

In order to determine the level of automation that exist within three representative NASA Mission Control Centers, the three basic functions performed by their respective flight operations teams were studied. This specifically included their methods for performing real-time monitoring and commanding, mission planning, and offline trend analysis.

Overall, there are varying degrees of automation within the NASA Mission Control Centers. The level of automation that is achieved is largely dependent on the level of complexity of the mission, as well as the capabilities of the ground system that they use. Larger missions tend to be less automated than smaller missions. This is not only due to technical barriers within the operations of larger missions, but it is also due to political barriers in automating the more costly and highly visible missions.

This paper will summarize current mission control procedures and suggest three specific areas for potential cost reduction through increased automation.



**Commanding the Spacecraft.** Commanding the spacecraft refers to the signals or telemetry that are sent between the Mission Control Center and the spacecraft's on-board software. Specifically, this is comprised of the uplinks performed for sending commands and memory loads to the spacecraft and the downlinks performed to download health and safety and science data from the spacecraft. Uplinks or forward links provide the on-board system with instructions for spacecraft operations such as instrument pointing. The number of times per day that uplinks are required for sending command loads depends on the amount of commands required to operate the spacecraft and instruments and the amount of memory available on the spacecraft for storing commands. Downlinks are performed by downloading engineering and science data to the Mission Control Center either in real-time mode or by downloading stored data from the on-board solid state recorder. Real-time downlinks occur by directly transmitting telemetry data to the ground during a real-time support with the spacecraft. Solid state recorder downlinks occur during a real-time support as well, but the data that is downloaded has been previously stored on the recorder during times when the spacecraft is not in view of a ground station.

The spacecraft is typically controlled by either executing real-time or stored commands. Stored commanding is the most common method and involves the development of pre-planned command loads that are sent to the spacecraft's stored command processor during contacts with the ground system. Each stored command is programmed to execute at a specific time to perform predetermined tasks. Real-time commanding involves the Flight Controller directly controlling the spacecraft by sending it commands that are executed by the spacecraft immediately upon receipt.

Real-time commanding is typically performed for routine activities where the Flight Controller requires feedback from the spacecraft (i.e., telemetry) while commanding. Examples might include managing the dumping of the on-board recorder and performing maneuvers. In certain emergency situations, such as when the spacecraft's state of health is in danger and there is no time to generate a stored command load, the Flight Controller may need to utilize real-time commanding.

There are two different methods used as a communication link between the spacecraft and the Mission Control Center: ground stations and the Tracking & Data Relay Satellites (TDRS). Ground stations are communication stations that are located all over the world and serve as the first communication point for the transmission of telemetry data from satellites to the ground system. The TDRS satellites are a constellation of six satellites which form the space-based portion of NASA's Space Network that support communication with other satellites from space. Requests for the use of any of the TDRS satellites are scheduled through the Network Control Center (NCC).

**Mission Planning.** Mission planning involves all of the activities required to plan for the contacts with the spacecraft. Specifically, this involves the coordination between different organizations to schedule the use of either TDRS or a ground station during times when a particular satellite is in view. Typically, Mission Control Centers use a flight dynamics system to generate orbit data that is factored into the communication schedule.

Additionally, mission planning involves building the commands that are sent to the spacecraft to control and instruct it. For large missions, there is a separate mission planning team that is responsible for coordinating the schedule for contacts with the spacecraft and building the command loads. For smaller missions, these functions are typically performed by the Flight Controllers.

**Trend Analysis.** Trend analysis is the analysis of spacecraft engineering telemetry data for the purpose of predicting potential anomalies that may occur in spacecraft components. Analysis of this data must be performed regularly to ensure that the science instruments are operating properly so that they can make accurate observations. Additionally, this analysis may prevent unsafe conditions which could cause the loss of an instrument or other component. The telemetry data typically gets automatically transferred from the ground system to an analysis system within the Mission Control Center that archives and stores it. Various types of statistical reports may be run by retrieving and plotting this data.

## Mission Observations/Interviews

Three representative NASA Mission Control Centers were observed in order to analyze their daily operations by physically sitting with the Flight Operations Teams and documenting their activities. Interviews were also conducted with team members to elicit feedback. The missions studied were: the Small Explorer (SMEX) missions, the Earth Observing System (EOS) Terra mission, and the Hubble Space Telescope (HST) mission. A summary is provided of each mission's procedures and level of automation.

**Small Explorer (SMEX) Missions.** The SMEX Mission Control Center is considered a multi-mission facility; each mission operates independently, yet consistently. The missions that are supported by this Control Center are: Wide-Field Infrared Explorer (WIRE), Transition Region and Coronal Explorer (TRACE), Submillimeter Wave Astronomy Satellite (SWAS), and Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX).

Their nominal staffed operations are for 8 hours a day, 5 days a week. They are not required to support a 24-hour a day, 7-day work week due to the level of automation that they have achieved in support of these missions. They have successfully automated the conduct of all of their spacecraft contacts, which includes configuring the spacecraft and ground system for the contact, dumping the solid state recorder, and monitoring the real-time health and safety data. However, they do still manually transmit their command loads.

The ground system that all four of the SMEX missions use to support their mission operations is the Integrated Test and Operations System (ITOS). ITOS merely uses System Test and Operations Language (STOL) procedures to automate the monitoring of the system during operator off-duty hours. The primary communication links between the spacecraft and ITOS are the Wallops Island and Poker Flat ground stations. These missions also rely on the Spacecraft Emergency Response System (SERS) to page the appropriate engineer if the ITOS system detects a potential problem in the spacecraft data that is automatically downloaded during off-duty hours. The ITOS interfaces with the SERS to execute this process.

The SMEX mission planning function is performed manually by the Flight Controllers. The system that they use to build their command loads is the Command Management System (CMS). The Flight Controllers prepare their own command loads using the CMS to build them. Although the CMS simplifies the building of the command loads, it appeared that many of the tasks performed were performed manually, such as the retrieval of the new procedures and the transfer of the old procedures to an archive directory within the system. The communication schedule for spacecraft contacts is prepared by the Wallops Planning System network and a weekly schedule is sent to the SMEX facility.

The trend analysis system that SMEX uses is the Data Trending and Analysis System (DTAS). The ITOS system provides DTAS with the telemetry data that it gathered and processed during contacts with the spacecraft. The data is used to make predictions by looking at overall trends. The team notes degradation in equipment and predicts failures with these reports. DTAS has successfully automated some of the reporting that is performed by these missions, such as automatically performing their daily trending plots.

In general, the SMEX missions are much more automated than the other missions that were studied. This can be attributed primarily to their ground system, ITOS, which provides them with the capability of automating their commanding and the relative simplicity of operating the missions. ITOS was used to its fullest capacity for the Fast Auroral Snapshot Explorer (FAST) mission that has now been moved to Berkley, CA. This mission was fully autonomous, except for their mission planning, for three months before it was moved. The engineers supporting this mission attribute its success to the stability of the spacecraft and the number of opportunities for making contact with it. The greater the number of opportunities for contacts, the safer automation is for a particular mission in that if errors occur in a transmission, there are more opportunities to recover or resend any lost data. Therefore, the greatest barrier for full automation of the commanding for the other SMEX missions is that there are problems at times with lost data that tends to occur at the ground stations. Skilled engineers are required to troubleshoot these problems.

**Hubble Space Telescope (HST) Mission.** HST is considered a Great Observatory mission, which is designated by NASA as a long term space-based general observer facility. Due to the size and public exposure of this mission, it is heavily manned and most of their operations are performed manually. The team supports 24 hour a day, 7 days a week nominal operations.

The HST Flight Operations Team (FOT) uses the Control Center System (CCS) as their ground system. Hubble typically uses one of the TDRS satellites as its primary communication link to CCS. The commanding that they perform through CCS is still for the most part manual in that all of the contact with Hubble to send command loads to the spacecraft are performed by the Flight Operations Team. Their command loads that support a 24-hour timeperiod include procedures that execute at predefined times to automatically downlink engineering and science data. The monitoring of the engineering data is performed manually 24 hours a day by the Flight Operations Team.

The HST mission planning function is now performed at the STScI, therefore a thorough study of this function was outside the scope of this study.

The Hubble trend analysis function is a fairly manual process. The Hubble System Engineers perform the analysis of this engineering data daily by extrapolating telemetry data from the electronic data warehouse in CCS to run reports. They import the data into either Microsoft Word or Excel and manipulate it according to the type of report they need to run and develop their own reports. The trend analysis function is definitely a candidate for further automation, as it requires the engineers to perform most of this work manually.

The lack of automation in Hubble's flight operations does not appear to be for technical reasons. Rather, it is more of a perceived political impact that prevents further automation. To a certain extent, their continued manual processes can be attributed to the high visibility of this mission, the impact to the science community if observation time is lost, the spacecraft changes that occur with each servicing mission, and the risk of damaging publicity if anomalies occur or data is lost during an automated pass. There are plans for upgrading their ground system sometime in the future to increase their levels of automation, particularly once servicing missions are no longer planned.

**Terra Mission.** The Terra Mission Control Center is part of NASA's Earth Sciences Enterprise (ESE) and is one of the Earth Observatory missions. It is also a very large mission and is comparable in size and complexity to Hubble. It has some of the same constraints with regard to automation as Hubble does due to its visibility and size. Although, the Terra Flight Operations Team is considering the implementation of further automation into their operations, currently all of their communication with the spacecraft is still performed manually. The FOT also manually monitors Terra's engineering data continuously throughout the day. The team supports 24 hour a day, 7 days a week nominal operations.

The ground system that the Terra Flight Operations Team uses to support their real time commanding and monitoring is the Eclipse system. The primary communication link between the spacecraft and Eclipse are the TDRS satellites.

The Terra mission planning function is supported by a team of people that are responsible for developing the following planning products: the Detailed Activity Schedule, which is a daily schedule that outlines all on-board activities for the next day, the NCC schedule request for TDRS supports, the ground station schedule request, the command loads prepared for uplinking to Terra, and several different types of reports for engineer and FOT review.

They perform these tasks using the Mission Management System (MMS) to develop their planning products. MMS does provide the planning staff with a certain level of automation that simplifies the preparation of these products and it will generate routine stored command sequences automatically. However, there are still many tasks that require some labor-intensive work by the planning staff and that could be further automated. As an example, the planning team must execute the scripts that automate their processes by entering in several UNIX commands in multiple UNIX terminal sessions. All in all, further automation of the mission planning process would simplify these procedures for the planning staff, although they have made definite strides in automating a great deal of their tasks.

The trend analysis system that is used by the Terra engineers is supported by the Epoch 2000 system, which performs the telemetry processing, and the Archive Browser and Extractor (ABE) system. ABE is used to retrieve and analyze the Terra engineering data and to generate trending reports. The ABE system automatically generates batch reports on a daily basis for the engineers to review. In most cases, the engineers use the ABE system themselves and generate their own reports. Some of this daily routine reporting performed by the engineers could be further automated. Furthermore, all of the analysis and predictions made by the engineers is performed manually. If the analysis of this data were automated, more of the data could be analyzed and the process of predicting potential anomalies would become much more efficient.

On the whole, additional automation for the Terra FOT could significantly improve their processes. Originally, they had planned to implement a system called the Flight Operations Segment (FOS), which would have automated more of their commanding, however this system was very unreliable and had to be replaced with the current Eclipse system one year before the launch of Terra. One of the barriers to automating more of their commanding processes is that the Eclipse system must interface with other systems to perform typical ground system functions. Increasing the degree that their systems are integrated could greatly facilitate the incorporation of increased automation throughout the system. Another barrier that inhibits additional automation within the FOT is that the data rates for communication between the solid state recorder and the Terra instruments vary throughout the day, depending on instrument activities. It would be very difficult, if not impossible, to model this dynamic process with the current Eclipse system.

## Conclusions

Overall, the larger missions (Terra and Hubble) were much less automated than the smaller missions (SMEX). This is not only due to technical barriers, such as the limitations of their ground systems, but it is also due to the higher complexity and visibility, as well as the unique culture of the larger missions.

The capabilities of the ground system that are used by the mission are a major factor that determines the level of automation. For example, the ITOS system used by the SMEX missions provides the capability of fully automating their commanding. On the other hand, the CCS system used by Hubble does not currently provide this capability and neither does the Eclipse system that is used by Terra.

Additionally, cultural and political barriers determine the level of automation as well. For example, in all of the missions that were studied, it was difficult for the engineers that support flight operations to fully trust an automated system to perform the critical function of communication with the spacecraft. There are legitimate concerns for the loss of data during an automated transmission that may not be recoverable if an engineer is not alerted to the problem in time. In the case of the larger missions, missing data would be very politically damaging and could impact funding for the project. However, for the smaller missions, these issues are not as much of a concern since the science data gathered by the smaller missions is not as publically followed as with the larger missions.

There are three potential candidates for further automation within flight operations. First, the mission planning systems for each of the missions studied all provided some level of automation for building schedules and command loads, but they all still tended to require a great deal of manual transferring of files, preparation of reports, etc. Second, the trend analysis functions for each mission are still manual to semi-automated in nature. While Hubble does not even have a dedicated trend analysis system, the SMEX and Terra operations have dedicated systems but there is still a fair amount of manual reporting that is performed. Additionally, the analysis and predictions of the data that are trended is performed manually for all of the missions that were studied. Lastly, commanding could be further automated, especially for the larger missions that still perform manual commanding for the downlinking of data. The FAST mission was the only mission studied that successfully automated the uplinking of command loads, although this function could also be automated for other missions as well. The FAST mission was one of the smaller class missions and was a stable noncomplex spacecraft.

The SMEX missions were the most successful of the missions that were evaluated in automating their flight operations. Surprisingly, they accomplished this by using unsophisticated automation techniques, such as the use of STOL procedures for off-duty monitoring. In contrast to this, AI automation techniques, such as expert systems, are much more complex and time consuming to implement. For example, expert systems that have been implemented within other NASA missions, such as GRO and RXTE, have taken much longer to implement than originally anticipated. This is due to the fact that it is very difficult to capture the knowledge of the Flight Controllers into a set of rules that can be used within the expert systems. It is also time consuming to test the rules to ensure that they are completely accurate. Consequently, it is questionable whether implementing AI technology within small to medium sized Mission Control Centers is worth the time investment. For large, complex, and long-duration missions, the implementation of expert systems is more cost effective.

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