Design and Creation of a Mission Control Center for Georgia Tech Satellites

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The Mission Control Center (MCC) at the Georgia Institute of Technology (Georgia Tech) endeavors to create a cohesive mission operations system that is configurable for any small satellite mission designed and built at Georgia Tech. The MCC is designed to provide an industry-quality mission control and the accompanying software to centralize the efforts required to operate a satellite, including receiving telemetry, sending commands, and processing telemetry to create understandable data outputs. The MCC will enter into service beginning with the upcoming launch of CubeSat GT-1. The process of preparation for operations primarily includes developing the software system to operate from the beginning of the satellite pass through data archival and developing an understanding of the key telemetry of the mission to sufficiently represent the statuses of mission critical components on the satellite in display visuals.

I. Introduction

In the past decade, the spac industry has embraced the use of smaller spacecraft, such as CubeSats, for exploration and technology demonstration purposes. University laboratories have become major contributors to the design and manufacturing of such low cost and rapidly built small satellites. The Georgia Institute of Technology's (Georgia Tech) Space System Design Lab (SSDL) has been actively involved in this process and successful in the launch of two satellites to date. In December 2018, the double 1.5U CubeSat Ranging and Nanosatellite Guidance Experiment (RANGE) was launched and began its mission of improving nanosatellite positioning capabilities [1]. Not long after in June 2019, SSDL's Prox-1 launched with deployable LightSail-A, a solar-sail driven satellite [2]. In the next year, SSDL intends to launch two more satellites, GT-1 and TARGIT, with more satellites of increasing mission complexity to follow.

Critical to the success of these satellites is the communication of data between the satellite and the mission operator. While there has been sufficient software and hardware infrastructure in place via the ground station to receive and send communications on a scheduled basis, the Georgia Tech system has been lacking a means for live decoding and visualization of satellite telemetry. Especially as SSDL satellite missions become more complex in their scientific objectives, there is a growing need for the timely decoding and processing of satellite data and an equally expeditious method for sending commands to the satellite in response. Since Spring 2019, the SSDL has been designing and creating the Georgia Tech Mission Control Center (MCC) to provide the physical space and software tools capable of serving as the link between satellite and mission operators. In preparing to be a multi-satellite service provider, the primary challenges faced by the MCC are creating modifiable software to fit many different missions and multiple missions at once, securing a reliable link to the ground station (GS) to relay data to MCC, developing customer relationships with satellite teams in the SSDL, and designing an MCC that is functionally and aesthetically industry-grade.

This paper will delve into the objectives and challenges of the MCC as a provider for several satellite missions (Section II), as well as the intended operational flow for the MCC to meet those requirements (Section III). Next, the content will shift to sources of influence and motivation for the industry-style appearance of the data displays and the MCC room (Section IV). Then, an example of MCC operations, including display design and communications

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specifics, will be explained for the upcoming GT-1 mission (Section V). Finally, several future goals and challenges will be explored (Section VI).

II. Objectives for the Mission Control Center

In general, a mission control center has several primary responsibilities in the scope of a satellite mission. These general functions are essential for the MCC to provide as services to Georgia Tech satellite missions. As described by NASA in their *State of the Art of Small Spacecraft Technology* guide, these key components are Ground Software, Reporting, Orbit Determination, Pass Predictions, Command Sequencing, and Data Management [3]. Though several of these functions have been built and utilized for previous SSDL missions, not all of the mission control center critical elements have been fully developed for more than individual mission use, and efforts have been widely decentralized. For example, for the RANGE mission, the Command Sequencing software was specifically written for that mission by the lab and interfaced with Ground Software via in-house, non- generalized software. Reporting and Data Management were primarily conducted through bot-notifications via the Slack messaging platform (Figure 1) and by archiving pass data on a single desktop functioning as the GS computer. The software for this mission could not be easily repurposed for future missions, resulting in non- recurring engineering for each additional mission.


RANGE Ops Notifier APP 2:30 PM

2 beacons from 20210328_165104 to 20210328_165104

	Pass	timestamp	eps_battv	eps_incur	eps_syscur	curr_state
0	20210328_165104	972864024	14002	421	169	6
1	20210328_165104	972864085	13765	415	446	11

Figure 1. Slack-Bot notification for RANGE beacon data.

In addition to creating reliable systems for each MCC function, another objective in creating the MCC is to centralize these functions with respect to software/hardware. At a minimum, the MCC should be capable of initializing all major functions (pass prediction, commanding, etc). Table I details the MCC objectives in terms of success criteria, including basic functional criteria and requirements as determined by the team to be critical to operation.

Table I. Operational success criteria for the MCC.

Objective	Minimum Criteria	Full Criteria
Ground Software		
The MCC shall be capable of establishing a link to the ground station of Montgomery Knight such that satellite data and commands can be passed to and from the ground station computer.	**X**	**X**
The MCC shall be capable of establishing a link to every affiliated Georgia Tech ground station (Montgomery Knight, Van Leer, Cobb County) such that satellite data and commands can be passed to and from the ground station computer.		**X**
Command Sequencing		
The MCC shall be capable of sending commands for each satellite mission from the mission control room.	**X**	**X**
The MCC shall have a system for sequencing commands for each satellite mission.	**X**	**X**
The MCC shall display the process of sequencing and sending commands as a component of satellite mission visualization.		**X**
The MCC shall automate the process of queuing and sending commands such that a contact may be completed for any pass at any hour without direct human engagement.		**X**

Data Management		
The MCC shall implement a data archival system for each satellite mission to store all previous pass data.	**X**	**X**
Reporting/Displays		
The MCC shall visualize all mission critical data (as decided between MCC and satellite teams) on display screen(s) in the mission control room.	**X**	**X**
The MCC shall use an automatic display system that shows updates in pass predictions and new pass data at any time.	**X**	**X**
The MCC shall visualize all satellite telemetry for each pass on display screen(s) in the mission control room.		**X**
Pass Predictions		
The MCC shall utilize propagating software to visualize the updated orbital position and drive the transition between passes of the satellite mission(s).	**X**	**X**
The MCC shall enable scheduling of future contacts and shall execute passes semi-autonomously without direct human engagement.	**X**	**X**

While much of the MCC can be designed such that the systems uniformly work for any satellite mission, there are elements including command sequencing and determination of mission critical data that require full understanding of the mission objectives of each satellite mission and considerable interaction between the MCC and satellite design teams. First, to better understand the required scope of change in operations, the team considers the upcoming satellite missions in SSDL, GT-1 and TARGIT.

A. GT-1

GT-1 is the first in a series of 1U CubeSats to be designed and engineered in the SSDL for the demonstration of a rapid building phase with a reliable satellite bus. The first mission in the series focuses on launching an amateur radio payload, alongside other typical hardware such as the flight computer and health-status instrumentation [4]. As the first customer of the MCC, this satellite mission supplies the challenge of quickly developing and iterating on software for decoding and displaying key telemetry. This requires significant communication with the satellite team while developing the first version of the MCC.

B. TARGIT

The Tethering and Ranging Mission of the Georgia Institute of Technology (TARGIT) is a NASA Undergraduate Student Instrument Program (USIP) sponsored 3U CubeSat that uses laser altimetry to obtain topographic information about a deployed inflatable tethered to the spacecraft. This will be tested with the intention of technological advancement in the realm of topographic investigation of other planets and bodies. The primary challenges presented to MCC for this mission will be integrating with a new commanding system as well as establishing the software infrastructure to reliably downlink and display images from the LiDAR imaging system [5].

GT-1 and TARGIT, as well as additional upcoming missions, require individual attention from the MCC team in order to tailor software to the needs of each mission. As a case study example, the MCC operations for GT-1 are detailed in Section V.

III. Operations of the Mission Control Center

In an effort to create one cohesive process for downlinking and commanding during a pass, all functions of the MCC are consolidated into one operational process, shown below in Figure 2. The Ground Station Component consists of the antenna and GS computer, both hosted in the Montgomery Knight building at Georgia Tech. The connection between GS and MCC is established wirelessly via a designated Internet Protocol (IP) Port on the ground station computer that allows data to be sent to and from the MCC computer. The MCC Component consists of the computers and display in room 301 in the Engineering, Science & Materials (ESM) building on the Georgia Tech campus.

Following the operational flow for a satellite pass, the satellite begins its pass overhead of the antenna. The antenna, automated by pass scheduler software in the GS computer, moves to track the satellite along its pass and receives the downlink signal. The downlinked data is received at the GS computer, which is then queried by the MCC computer to send the pass data. The MCC computers utilize software to then process, decode, visualize, and archive the data. More details for each function are in the sections that follow.

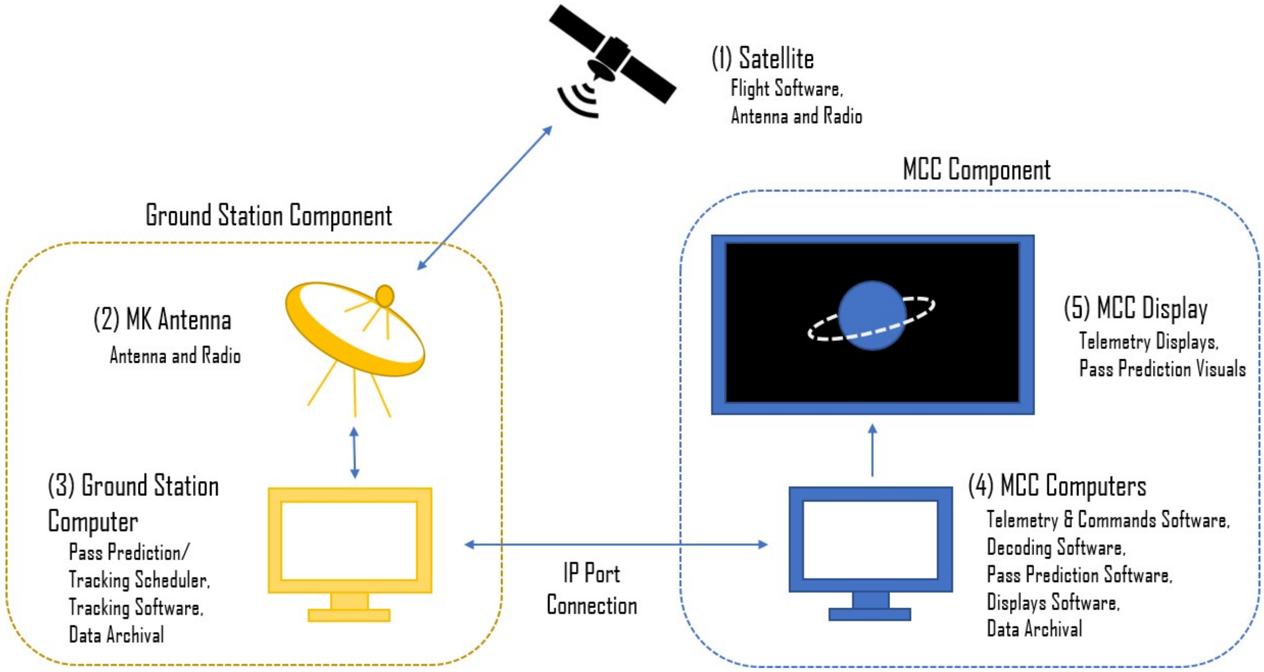

Figure 2. MCC operational diagram considering all major hardware and software functions.

A. Ground Station Component

In current operations, the GS in use by the MCC is located in the Montgomery Knight building on Georgia Tech campus. The antenna is positioned on the roof of the building with an accompanying computer equipped to schedule passes and automatically move the rotor to track the satellite in its pass. An image of the antenna and key information are displayed below in Figure 3. Other Georgia Tech ground stations, such as those at Van Leer and in the Cobb Country Georgia Tech Research Institute (GTRI) facility, will be coordinated with in the future to provide improved satellite access during multiple-satellite operations.

Location	Georgia Tech Montgomery Knight Building (33.772316, -84.395969)
Tx	430-440 MHz
Rx	430-440 MHz
EIRP	30.67 dBw
Gain	18.9 dBi
Polarity	RHCP
Antenna	M2 436CP42UG
Alternative Antenna	M2 2MCP22 (VHF antenna) M2 2305 MHz Septum Feed (inactive)
Radio	Ettus B210
Alternative Radio	Kenwood TS-2000
Rotors	M2 Azimuth/Elevation Positioners (Multi-Speed Motors)

Figure 3. Montgomery Knight antenna and hardware component information.

B. MCC Component

The MCC room in ESM 301 (Figure 4) contains several desktop computers and a display screen for visualizing pass prediction information and telemetry. The computers are used as consoles for simulating passes to obtain accurate estimates for pass timing and position, as well as for queuing and sending satellite commands. A crucial component of the console for commanding the satellites is the Telemetry & Command Software. Generically speaking, this software is mission-specific and either written or tailored by the satellite design team to be conducive to their program. For the purposes of the MCC, this software must recognize (typically through a dictionary) all of the satellite's data outputs and accepted commands. With the connection to GS enabled, this software is the initial receiver of the telemetry within the MCC to decode the data and pass it to other software that allow for interpretation and visualization on the display. Similarly, the software permits the sequencing and sending of commands via the port as well.

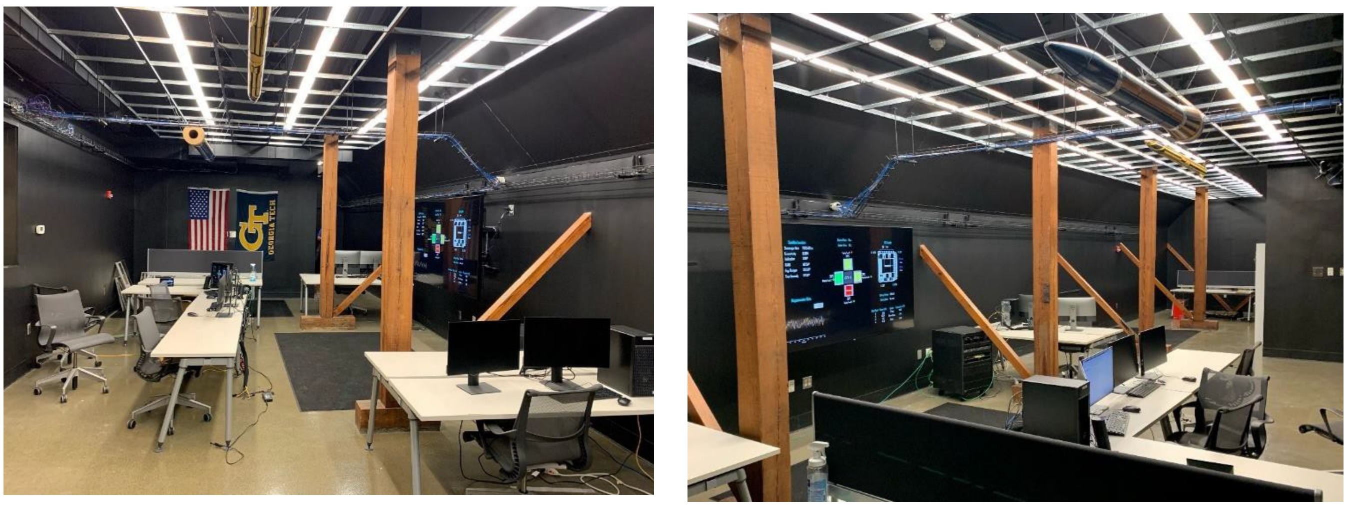

Figure 4. Mission control room in Engineering Science and Mechanics Building Room 301 on Georgia Tech campus.

Once telemetry is received and unpacked by the Telemetry & Commands Software, an additional decoding script may be implemented to interpret the data as readable numbers and phrases. An example of this type of decoding would be converting hexadecimal files (containing binary information) to a spreadsheet with a row for each data point of interest. The data is then sent to the display software for visualization and to an archived folder for easy access in the event that further evaluation is necessary. These processes are further discussed in the study of MCC for GT-1 in Section V.

C. Operational Phases

As previously mentioned, there is a necessary sequence of operations between the satellite, ground station, and MCC in order to allow the proper intake and processing of telemetry at MCC. The MCC has elected to define this sequence in terms of three phases: Pre-Pass, During Pass, and Post-Pass. Each phase, described below in Table II, has its own critical functions. These phases rely heavily on the pass predictions that take place in the software of the GS computer and in the MCC computers. The initialization of the pass and the transition between each phase is determined by the pass start time and duration.

Table II. Satellite pass phase descriptions and activities (activities that require human action italicized).

Pre-Pass Phase	During Pass Phase	Post-Pass Phase
Pass Prediction (Pass Time, Azimuth, Elevation) *Preparing Command Sequences*	Antenna Rotor Movement, Receive Telemetry, Display Telemetry Stats, *Sending Commands*	Decode Telemetry, Process and Display Telemetry, Archive Pass Data

1. Pre-Pass Phase

This phase begins 10-15 minutes before the pass start time. During this time, the pass prediction tools in the GS and in MCC are operating to schedule the upcoming pass, as well as several passes into the future. The GS prediction tool drives the actual antenna rotor movement and the MCC prediction tool assists in timing the actions taken by the MCC software, such as querying GS for the pass data, commanding the satellite, and automatically displaying telemetry.

Meanwhile, MCC and satellite team members stationed in the mission control room prepare the commands for the upcoming pass using the Telemetry & Commands Software. This process will use a documented procedure of selecting from scripts of pre-written commands so as to simplify the process and to be able to test the reliability of the scripts before full operations. The MCC display shows the predicted azimuth and elevation path of the satellite as well as the upcoming schedule for all satellites being tracked.

2. During Pass Phase

At the predicted pass start time, the GS software begins to automatically point the antenna along the path of the satellite's pass. The communications signal is received by the antenna and into the computer at the GS. At this time, via the IP connection, the telemetry is sent to the MCC computer. This incoming data is visualized by a strip chart which shows incoming data packets as the pass continues. The team sends the prepared command sequence via the GS port. In-pass metrics will validate acquisition of signal, transmission of commands, and receipt of data.

3. Post-Pass Phase

At the conclusion of the pass, as timed by the pass prediction tools, the antenna and GS computer's roles are complete. The GS archives the data in the desktop files as a final step in the pass. All data has been passed to the Telemetry & Commands Software at this stage, where the telemetry is then processed and formatted for decoding. The decoding script then takes over and packages the string and number-formatted telemetry for display and archival. The display software visualizes, at a minimum, the telemetry that has been deemed most important. This includes science instrument data, health statuses (temperatures, battery charge, currents, bytes received by instruments, etc.), and general system data such as the time and state.

At the conclusion of the post-pass phase, the cycle repeats and moves into a new pre-pass phase for the next pass which could be minutes or hours away. It is the cyclic nature of the process that allows for simplification and minimal human interaction through the implementation of pass timers. This process is delved into further with respect to software for the case of the GT-1 satellite in Section V.

IV. Creating an Industry Appearance

A goal of the MCC that, though not mission-critical, has been prioritized in the past two years of work on the space has been to create an environment that emulates an industry-level mission control room. This design element of the MCC is intended to contribute both to publicity of and general interest in the SSDL, as well as to make the MCC more favorable to industry leaders for future contracted mission operations roles. The two primary ways this has been carried out are through the design of the room itself and creation of display visualizes that resemble those seen in industry control centers. The following images in Figure 5 compare the NASA Jet Propulsion Laboratory (JPL) mission control center in Pasadena, California, with the current state of the MCC.

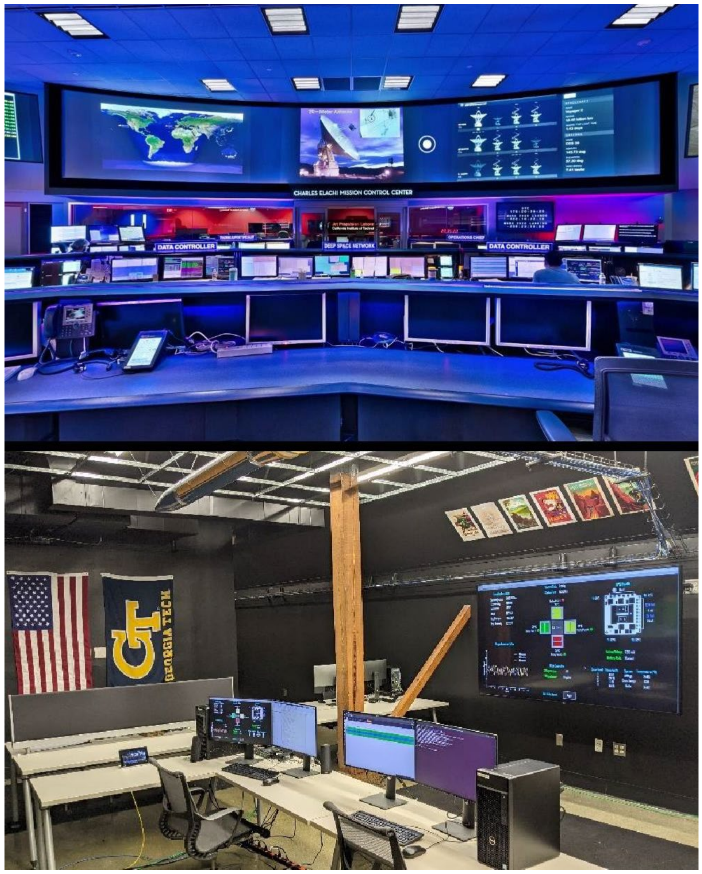

Figure 5. JPL mission control room [6] (top) and MCC room (bottom).

Other mission control rooms similar to JPL's were likewise examined in the early stages of MCC development to determine the necessary elements of the space as well as additions that could elevate the overall appearance. The team also analyzed what information was often presented on the displays in such mission control rooms. This information, along with software products for mission operations, were looked to as examples for the design of the displays. Of the software products referenced, the open-source COSMOS software by Ball Aerospace was the most influential to the design of the displays software for MCC. Images of example tools within the COSMOS system are shown below in Figure 6.

Overall, the COSMOS system contains most necessary ground operations functions for a satellite mission, including real-time scripting, commanding and data analysis. The system is equipped to be used during testing and operations phases of a mission. The tools in Figure 8 demonstrate only one element of COSMOS's functionality, the ability to display telemetry for specific downlinked packets, which was the main attribute that the team investigated [7]. Though COSMOS and other similar tools can simplify commanding and data visualization processes, these systems work best when implemented throughout the process as the scripting, commanding, and data analysis software. In order to be an effective provider for satellite missions at Georgia Tech, the MCC team decided to write software that could be used with any commanding and telemetry packing software that a satellite team may decide to use. In addition, the team decided that the visuals could be more appealing and tailored to each satellite if written in-house instead.

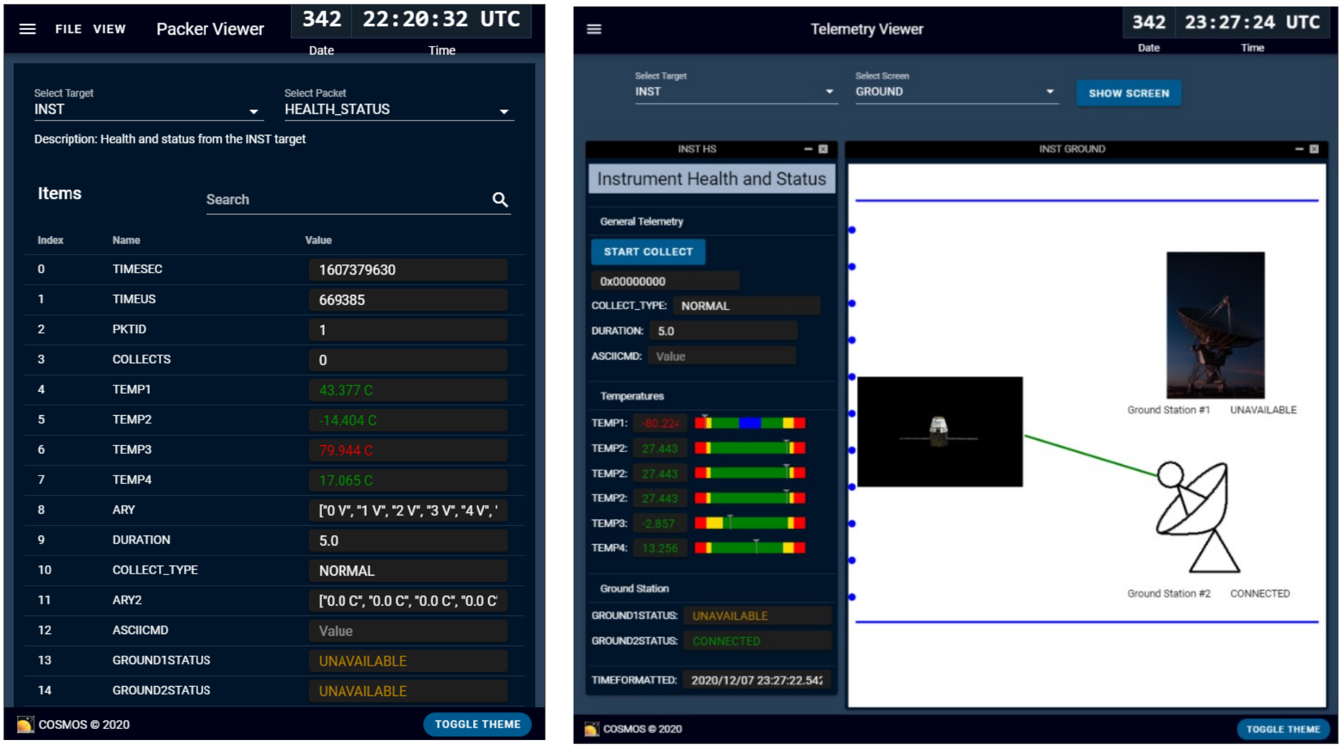

Figure 6. Packet Viewer and Telemetry Viewer windows for COSMOS system [7].

The insights that were gained from studying the COSMOS system predominantly related to effective ways to display telemetry. The concepts gathered from this research phase included utilizing standard colors to indicate limits violations for data, showing the antenna activity with an updating antenna image, and including the ability to toggle between data screens. The following section examines the implementation of these ideas in the displays, as well as the overall plan for GT-1 operations with respect to MCC.

V. GT-1 Example Operations and Displays

As noted previously, GT-1 is a 1U CubeSat built in the SSDL with intent to launch within the year 2021 (see Figure 9 below). GT-1 presents the opportunity to test the capabilities of the MCC on a relatively simple satellite mission. The satellite will launch with standard hardware: a flight computer, a battery and electrical power system (EPS) board, solar panels, a magnetometer, magnetorquers and a magnetorquer controller, a suite of temperature sensors, and associated wiring. As GT-1 is also the first in a series of 1U CubeSats to be produced, the series of missions allows the MCC procedures and software to improve as the satellites improve and add elements that require more complex visualization and data reduction.

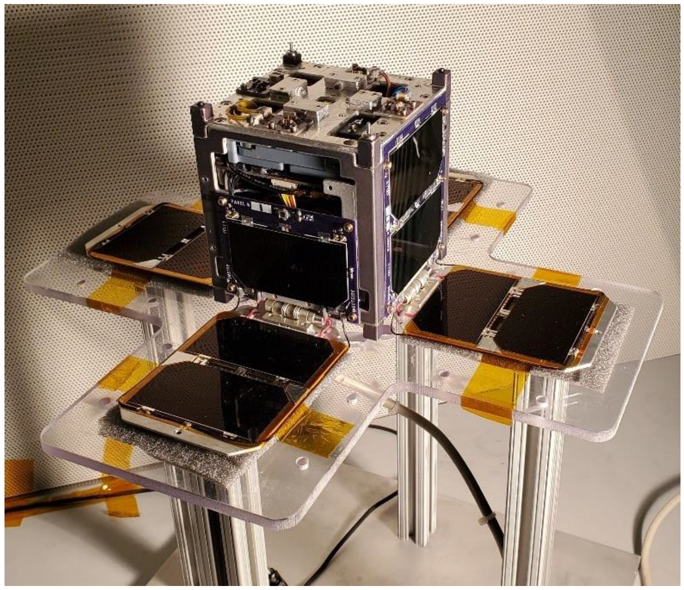

Figure 7. Integrated GT-1 CubeSat in stand with solar panels deployed.

The MCC process for GT-1 will follow the general operational flow as given in Section III and shown in Figure 2, with use of the pass phases detailed in Section III. The following sections are intended to describe the in-depth software and display details of the system.

A. MCC Software for GT-1

The MCC software procedure is designed to allow for the use of Telemetry & Commands software complimentary to the satellite's mission. GT-1 utilizes an open-source flight software from JPL called F-prime (F') that is specifically written to cater to small satellite missions. The tool within the F' suite that MCC interfaces with is the F' Ground Data System (GDS). The GDS supports telemetry file downlinking, command sequence assembly, and sending commands, among other functions. The F' GDS can be considered the key component to the overall software architecture within the MCC, as presented in Figure 8.

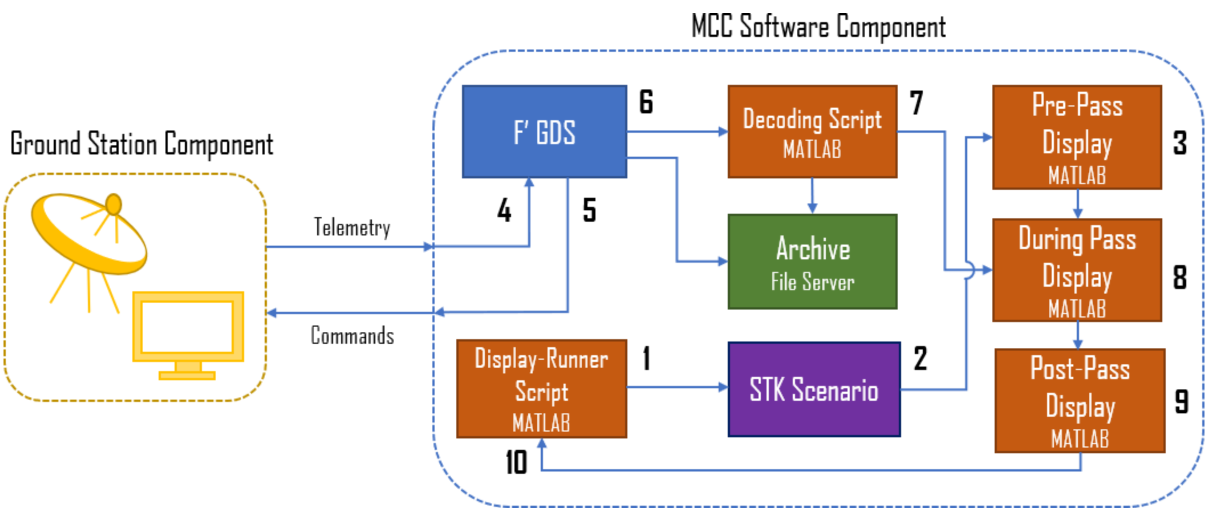

Figure 8. Software flow diagram focused on processes in the MCC.

The above diagram of the software system generalizes the GS. This system, which uses pass scheduling and tracking software, has been reliably used for past missions and, for the purpose of this study, can be considered to be a complete system.

As described in Figure 7, each activity in MCC can be mapped to a pass phase (pre, during, and post). In the software flow, the pre-pass phase can be explained by steps **1**-**3.** First, in step **1**, an automated MATLAB Display-Runner script, which calls to STK to generate pass predictions and functions as the framework for the displays, is initialized. In step **2**, the STK scenario is opened and updates the scenario time frame for a current propagation. As instructed by the script, the STK scenario outputs table files of the pass schedule, including start and stop times and iterations of azimuth and elevation to track the satellite's motion during each pass. In step **3**, the output pass schedules are passed to the MATLAB App Designer code for the Pre-Pass Display. The Pre-Pass Display script produces timer-based visualizations for the upcoming pass and lists the predicted pass schedule. It is important to note that the Display-Runner script, STK scenario, and Pre-Pass Display can all accommodate multiple satellites at once.

The during pass phase can be described by steps **4**-**8** in the above diagram. This phase begins with the reception of telemetry files from GS at step **4**. For the GT-1 mission, data will be received in the form of 15-second beacons sent in series during a pass. Each beacon will transmit to GS and then be sent to MCC. F' receives the telemetry and packages it as log files partitioned per beacon and written in hexadecimal. In step **5**, which also begins at the start of the pass, the commands that had been prepared for the pass are sent. The log files from F' are sent to two destinations in step **7**: the archive and the Decoding Script. The log files are archived as a redundant method for data analysis should an issue arise from the decoding step. The MATLAB-written Decoding Script takes in the log files as input and outputs tables of telemetry in numerical and string formats. This script utilizes the anticipated beacon sizes and telemetry variable names for GT-1 to structure the data tables. Finally, in step **8**, the telemetry is passed to the During Pass Display code. This is done iteratively, as the Decoding Script continues to send decoded beacons to the display until the pass concludes. The influx of telemetry is visualized in the During Pass Display.

Finally, steps **9** and **10** depict the software activities in the post-pass phase. The concatenated beacon data files are sent to the Post-Pass Display to visualize the data for the full pass in step **9**. This display utilizes multiple tabs for each major subsystem to allow for multiple detailed plots to capture all telemetry and any fluctuations that occurred during the pass. The final event in the MCC software cycle, step **10**, is to restart the Display-Runner script once the Post-Display has been visible for a duration long enough to note the behaviors of the satellite in that pass, or until the next high-priority pass begins.

B. Key Telemetry for GT-1

A critical step in coordination with the GT-1 satellite team was to determine the key telemetry that needed to be conveyed in the During Pass and Post-Pass displays. The display visuals allow satellite operators to quickly spot and react to erroneous or out-of-bounds data. Given this, the content and layout of the displays significantly impacts the commands sent to the satellite in following passes.

The telemetry was divided into categories: Magnetometer/Magnetorquer Data, EPS Data, Software Data, and Statuses. Since GT-1 has limited hardware and software systems, the team was able to accommodate most telemetry for displays. The Magnetometer/Magnetorquer Data consists of magnitude and directional information for each of the instruments. The EPS category tracks all system temperatures, battery voltage, and currents in and out of the EPS board. The Software Data predominantly consists of counts for bytes and commands sent/received. Lastly, the Statuses category provides restart counts and system flags. For each telemetry variable, the decision was made whether to simply tabulate or plot the data, or to further process the data. Examples of these displays with the key telemetry are shown and explained in more detail in the following section.

C. Displays Software for GT-1

The primary objective of the displays software in the first iteration was to design displays that could be easily modified for any satellite mission to be operated by the MCC. This goal was accomplished by several design choices, the first of which was to create all displays software in the program MATLAB App Designer. MATLAB App Designer features drag-and-drop style visuals that allow for simple transitions between satellite missions. Given that most pre-pass and during pass operations are transferable from mission to mission, few modifications are required. In the post-pass phase, the displays require updates to the telemetry visuals, such as plots and tables, that can be implemented without overhauling the entire initial design. With a baseline model completed, the telemetry-based changes can be made on a shorter timeline.

In addition, the software behind the visuals was written to accommodate any number of satellites as given by satellite code (eg. PROX-1 44339). As the MCC grows to monitor more satellites, the pre-pass and during pass software will intake all pass data and iteratively sort to determine the next pass and the schedule of upcoming passes remaining, querying for the next set of up-to-date pass predictions from STK after each pass has occurred. With this feature, the pre-pass and during-pass prediction visuals only need to undergo maintenance and design-based updates from mission to mission.

1. Pre-Pass Displays

The first of the display modes, the pre-pass mode, visualizes the pass predication information for any number of satellites. As seen in Figure 9 below, a sky plot maps the upcoming passes' trajectory over the ground station in terms of azimuth and elevation. The pass schedule is in the upper right hand of the display, with up to three upcoming passes, times and durations marked. The location information and orbital elements are provided in the bottom left hand of the screen, as determined by STK. Finally, an antenna visual on the bottom right-hand of the display indicates the status of the pass. While uncolored, the pass has not yet occurred and the time until pass will iterate downward until the pass' beginning.

Figure 9. Pre-pass display mode main screen before the start of the pass.

The "Tab Mode" label at the bottom of the display reads either "Manual" or "Automatic." When the mode is manual, the display will remain on the current screen. While in automatic mode, the screen will rotate between tabs every 30 seconds. The second screen or tab in the pre-pass mode serves as a summary of the previous pass and shows various plots and tables that contain information from the most dynamic or change-prone satellite components.

2. During Pass Displays

In the during pass mode, shown in Figure 10, the main screen carries the pass schedule of the pre-pass main screen. The display utilizes the same antenna visual as well, this time indicating the pass start by turning green and showing the incoming data by dots approaching the antenna. When this occurs, the time left in the pass, azimuth and elevation also appear and change according to the anticipated live position of the satellite. The main screen also contains a strip chart of beacons as received by the MCC from GS, labeled "Incoming Beacons". This plot simply shows a marker for every beacon at the received time stamp in seconds after the beginning of the pass.

Figure 10. During pass display main screen when pass has started.

The during pass mode also utilizes tab modes to switch between manual and automatic screen rotation. The second screen for the during pass, shown in Figure 11, contains a condensed set of post-pass mode plots and tables. This set is intended to give rapidly processed information that provides insights to the telemetry as the pass occurs so that commands can be sent to the satellite if need be to remedy errors. The plots and tables are populated at the rate of each incoming beacon and resemble the strip chart.

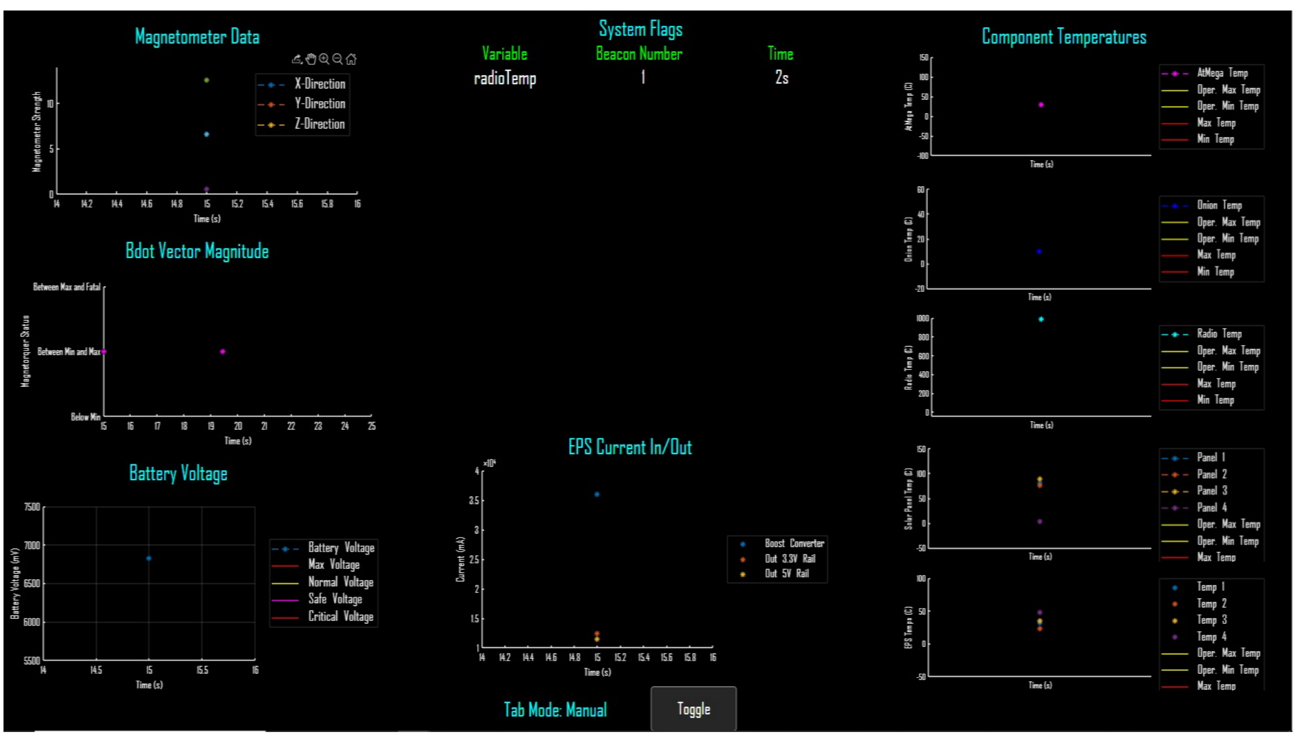

Figure 11. During pass display mode pass telemetry screen.

3. Post-Pass Displays

The post-pass display mode consists of several tabs that align with the distribution of telemetry as discussed in the Key Telemetry for GT-1 section. Each tab or screen in the mode attempts to summarize all patterns and behaviors of the data with respect to each component. These tabs are toggleable in the same manner as in the previous modes so that telemetry can be revisited and analyzed throughout the post-pass mode. The main screen, shown in Figure 12, provides an overview of the data for the entire pass, incorporating key findings from each telemetry subset. Note that all data shown for the post-pass display figures in this section is fake and contrived based on known limits of each component. The variation shown in the plots is to an unexpected degree.

The main screen shows the satellite location as predicted by STK, as well as the pass' system time and state, both attributes of each beacon. The EPS health is summarized by an EPS board visual with temperatures at the thermistor locations and currents in respective input and output locations. The solar panels that deploy from the faces of GT-1 are visualized in the center with colors that indicate the temperature status. Generically in this display, green indicates that the value is within operational bounds with contingency, yellow shows a value within regular operational bounds, and red demonstrates any value out of those bounds. The solar panel display also indicates the deployment status of each panel. The magnetometer data plot shows the time-wise variation in magnetic readings for each body-axis direction. The Bdot controller status is given in terms of whether each magnetorquer is operational. Finally, a brief table of further EPS status are displayed in the bottom right of the screen, giving abbreviated battery, solar panel, and other component statuses. The display is written such that the most recent beacon's telemetry is shown on the main screen unless there are anomalous values, in which case those are shown.

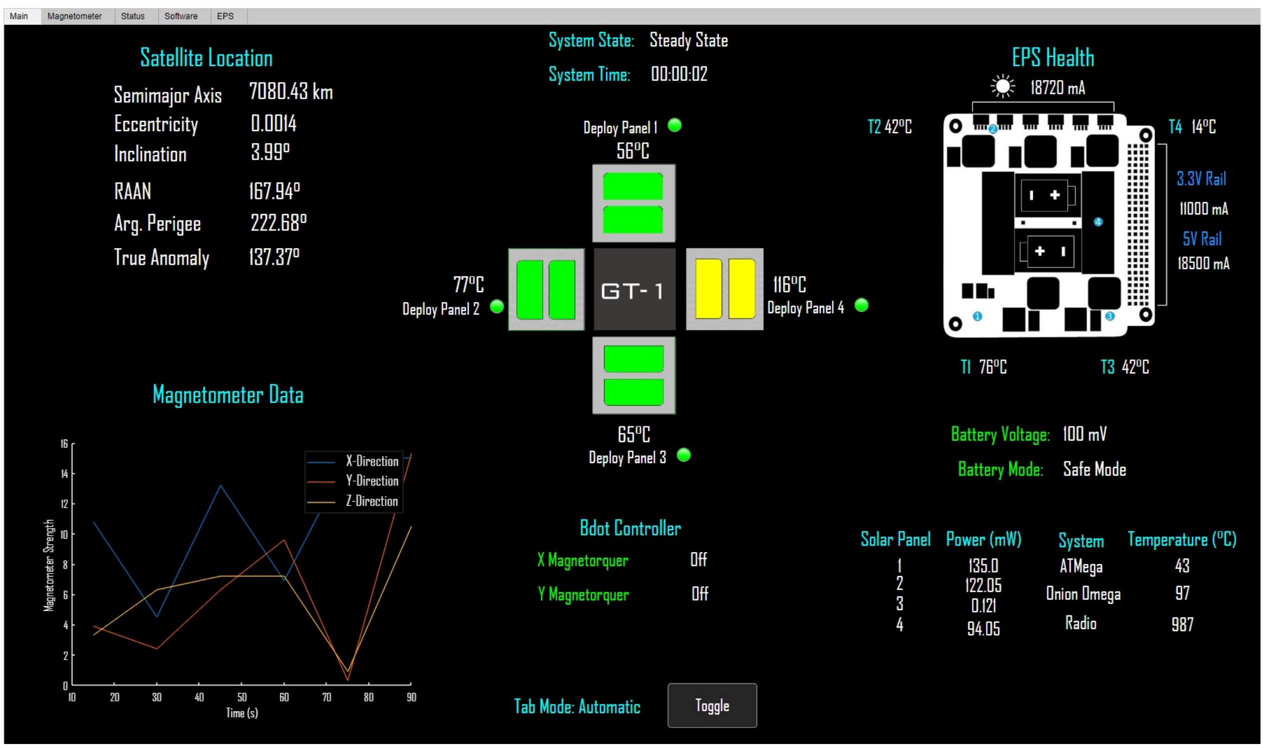

Figure 12. Post-pass display mode main screen.

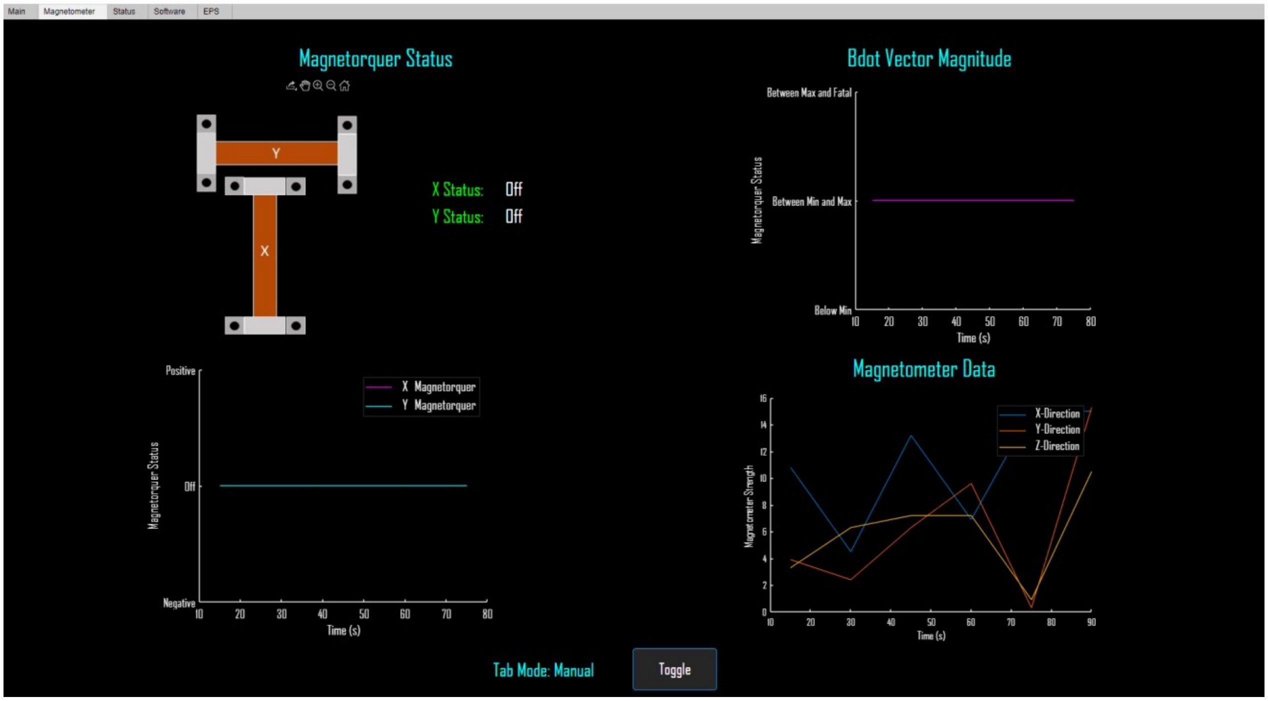

Figure 13. Post-pass display mode Magnetometer and Magnetorquer screen.

The telemetry associated with the magnetometer and the magnetorquers aboard GT-1 is joined in the second tab of the post-pass display mode, seen in Figure 13 above. The primary visual for this mode is the magnetorquer system, which demonstrates whether the magnetorquers are on and, if so, the direction of the current through the magnetorquers. The behavior of the magnetorquers is shown with respect to time, indicating a change in the direction over the course of each beacon. The combined operation of the magnetorquers determines the Bdot vector magnitude, which is plotted in the upper right of the screen. The plot is qualitative and describes the limits that the magnitude falls within during the pass as a function of time.

The following tab, shown in Figure 14, enumerates the general statuses and faults throughout the satellite system. The overall statuses from the main screen are carried over into the Status tab. The watchdog timer values are provided so that the operations team can monitor reset of the timers. Similarly, the latch up counts for the EPS board are tabulated. The central element to the Status tab is the System Flags table. The code for this mode considers every telemetry variable and compares against its system limits at each beacon. Any data found to be out of yellow or red bound is noted in the Systems Flags table. This system allows operators to observe and act upon the observed faults. This flags table is also utilized in the during pass mode (Figure 12) in order to display faults as the beacons arrive and as the data is processed.

Figure 14. Post-pass display mode Status screen.

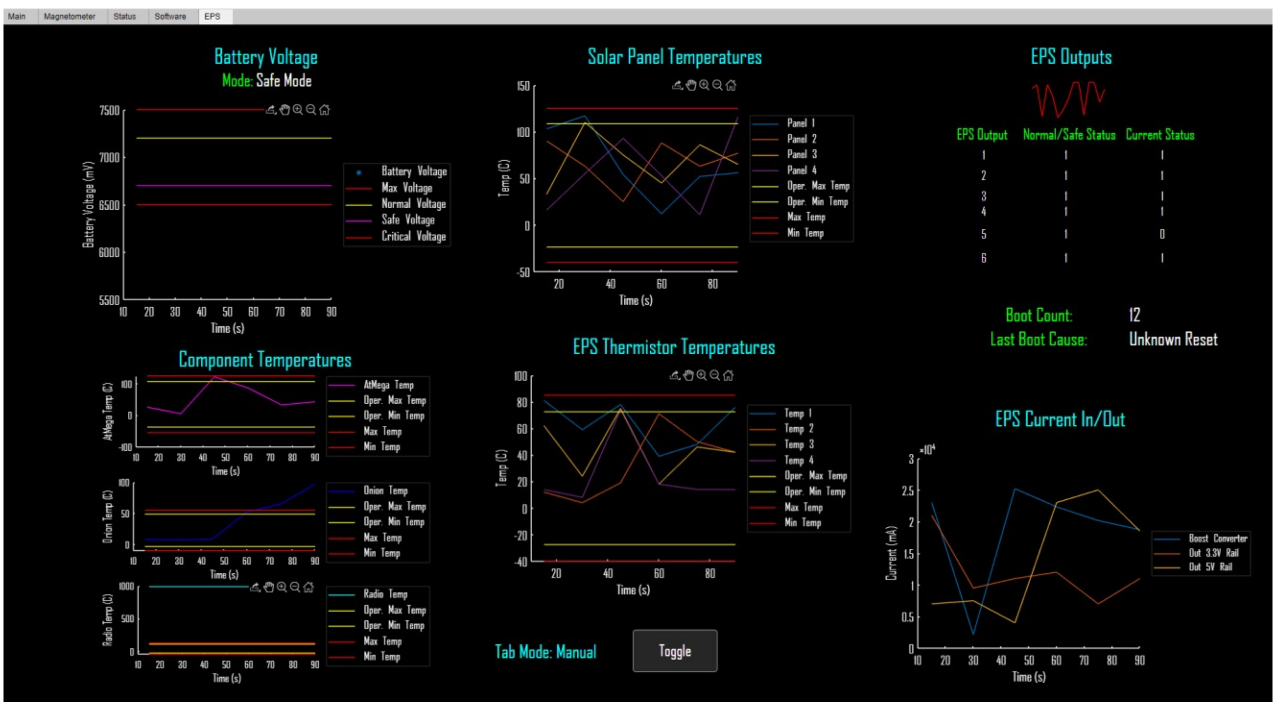

Figure 15. Post-pass display mode EPS screen.

The EPS tab in Figure 15 relies on plots of temperatures, voltages, and currents to convey the fluctuations in the system throughout the pass. The values are anticipated to be within yellow bounds and to vary minimally in each pass. These visuals, each with predetermined limits plotted, assist in determining if there have been anonamlous changes to the telemetry during the pass. The display software generates a temperature plot for each component with temperature monitoring. The battery charge during the pass as well as the status of the battery (eg. “Safe Mode,” “Critical Mode”) are displayed in the upper left of the tab. The EPS currents in and out of the board are plotted for each beacon.

The EPS outputs are tabulated in the upper right of the tab to show whether each output port of the six are operational. The ports are grouped together in two sets of three to make up the outputs for each of two voltage rails. The plot above the table serves to summarize the changes to the EPS output statuses throughout the pass. If there has been no fluctuation to the statuses, a green arrow will appear. If there has been a routine amount of fluctuation, such as one of the outputs in a group turning on and off during the pass, a blue sine-wave will show. A sporadic red plot will appear only when a significant amount of fluctuation has occurred, such as more than one output in a group being off for the duration of the pass, to indicate to the operators that the output data should be analyzed in further detail to investigate the issue.

D. MCC Functional Tests

Prior to the launch and deployment of GT-1, the software system running the MCC must be tested to demonstrate preparedness for operation. To date, two systems are in use or under development to effectively test the full system. The first, called BotSat, is a MATLAB script that randomizes satellite positions and timing in an STK scenario and runs the displays alongside an F' telemetry generator based on the GT-1 deployment. The pre-pass and during pass modes are tested to verify the correct generation of pass predictions for any set of satellites. The telemetry-based portion of the during pass and the post-pass modes are tested to determine reactions to changes in telemetry, such as out-of-bounds values or telemetry missing from the beacon.

The second method for testing, still under development, is GroundSat. GroundSat is a simple hardware system, primarily consisting of a radio, to replicate the communications system of GT-1. The system will be a simplified ground-based version of the satellite to allow the team to both test communications to the GS and monitor how beacons are received by the MCC. GroundSat will be implemented in Summer 2021 to demonstrate the full system from satellite to displays.

VI. Future Objectives and Operations

Throughout the process of designing the MCC, several additions to the system have been discussed for implementation in future semesters and further improvement of the MCC. The first of these updates, which is deemed mission critical, is to enable the connection between GS and MCC. This relies on the IP connection, which will be attainable after the addition of software at the GS that will be used to accept the connection. This modification is intended to be complete in Summer 2021, with necessary completion before the launch of GT-1.

Another objective that is intended to be completed prior to GT-1 launch is the incorporation of previous pass data into the post-pass app. This will allow for operators to more easily determine differences in component behavior. Finally, an update that does not require as much expediency but would benefit satellite operators is the addition of a web-based MCC portal. With the telemetry visual accessible online, operators would be able to monitor passes from outside of the MCC.

In future iterations of MCC for different satellite missions, the MCC is intended to be run by mission operators as delegated within the satellite team. In the early phases of operation, the MCC team will assist in monitoring and maintaining the software systems behind mission control as a part of the operations team. Future satellite missions will receive the MCC software packages and support as more so of a service from an outside provider. The ultimate intention is to elevate the reliability of the MCC system to the level at which the software can be used without dedicated support from the MCC team.

VII. Conclusion

Following the connection to ground station, the MCC will be fully operational and prepared to receive, decode, process, and visualize telemetry from GT-1 following its launch and deployment from the International Space Station. Testing completed using BotSat and GroundSat will serve as confirmation of the GS connection for data reception and sending commands, as well as assurance of the operation of the displays software. The visuals created for the GT-1 mission will provide general insights of the satellite status and inform satellite operators in decisions to send commands. In the early phases of mission operations for GT-1, the MCC team will be able to iterate on the design of the MCC system and implement changes as the mission continues. With each satellite mission operated in the MCC, the system will be updated to reflect new insights for ways to improve the system. The intention is that, within years of operational practice, the MCC will be fully functional for any satellite team with a reusable software system and industry-grade control room at their disposal.

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