Display System for Columbia Space Initiative's CubeSat Mission

Astro Girls
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Section I: Abstract

This paper describes the design and human factor evaluation of a mission control system developed to support Columbia Space Initiative (CSI) students in monitoring and operating the CubeSat LIONESS. The CubeSat refers to a modular design of each U being 10x10x10 cm. LIONESS is a 6U CubeSat, meaning its dimensions are 10x20x30 cm. The LIONESS payload is a miniature telescope that collects spectroscopic data on the Hydrogen Alpha emissions around distant galaxies. Scientific data is collected and analyzed outside of the designed display. After launch, it is important that students at CSI can monitor the CubeSat health data and uplink and downlink commands during windows where the CubeSat antenna is pointed and within range of our ground station. The designed user interface aims to simplify mission operations by integrating critical information into a single platform. To determine flaws in our system and the optimal design, we have selected CSI members to complete a series of realistic mission tasks, half using an integrated display and half using a separate display with two different command input methods. We collected response times, error rates, and feedback during testing using a modified Cooper Harper scale to evaluate workload, usability, and overall user experience. The results will direct us in a system redesign to meet the user and mission requirements more efficiently. Overall, our work will be a step forward in constructing a user interface for CSI's LIONESS.

Section II: Existing systems for CubeSat control

Columbia Space Initiative's CubeSat mission currently does not have a display or control system, so we searched for other examples to compare our design. For an existing system display, we looked at the Mission Operation System Tool (MOST) developed from the Comprehensive Open architecture Space Mission Operations System (COSMOS) at the Hawaii Space Flight Laboratory (HSFL) [11] . For a flight display, we looked at the Ground Control Station for Drones by Drone Engr [2]. However, it is important to note that the designed system for Columbia's CubeSat will not have any direct operator flight controls since it is a satellite in orbit. The developed system focuses on user interaction with pseudo-code in response to data and warnings.

IIa: Existing Display System - MOST Hawaii Space Flight Laboratory (HSFL)

MOST was developed at the University of Hawaii at Manoa to support small aircraft operations like CubeSats [11]. It is intended for small operation teams with limited development and budget, perfect for a university team like CSI. This was our main reason for selecting this display; we wanted something simple and applicable to university-scale design.

MOST, shown in Figure 1, uses a Qt “widget” format to display satellite information, creating an interface between the satellite and the operator. The primary widgets show the orbit's position and attitude, time, warnings, payloads, battery, telemetry data, and past and present orbital and spacecraft events [11].

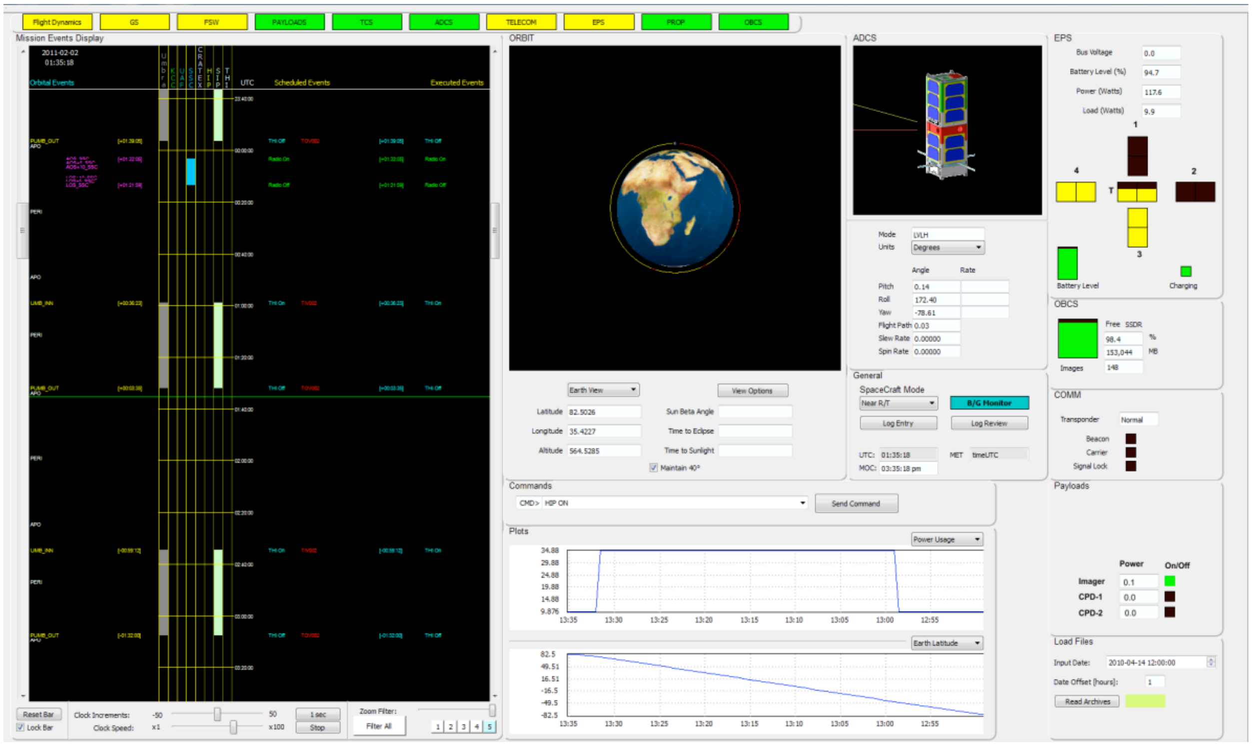


Figure 1. MOST Display for 3-U CubeSat [11]

The display is primarily automated from real-time data updates from a satellite, which are then displayed on widgets. Humans interact with the interface by interpreting data and making decisions based on their understanding of the information present in the system. In our display, we wanted to make it more interactive for the user, allowing for less dependence on automation.

MOST's design has several strengths we wanted to include in our system. For example, it replaces memory with real-time updates, conveys a high amount of information within the simple and understandable widget style, limits discriminability, has flexible configurations for specific missions, as a user can remove or add widgets based on their mission requirements, and implements some pictorial realism.

Despite its strengths, we saw some areas of improvement. For example, although the widgets provide a lot of information, they reduce legibility due to an overly cluttered display. Also, with the amount of text information conveyed, there needs to be more pictorial realism and the principle of moving parts, which was important to include in our display to allow the user to visualize the data in relation to the CubeSat. Figure 2, a cropped plot widget from MOST, illustrates an example where pictorial realism could be helpful with either a power bar illustration or a visualization of the CubeSat to Earth. Finally, the widgets are redundant, but the information within the widgets is not, making it difficult for the user to interact with and learn the system.

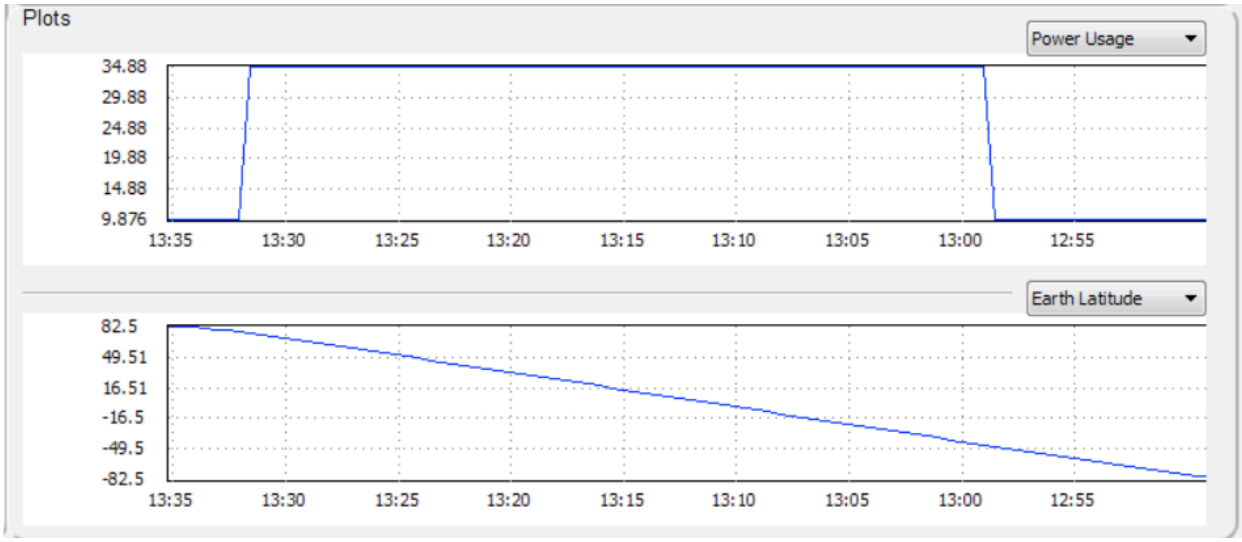


Figure 2. MOST Plot widget [11]

Another area for improvement is the warning system. The widget design makes it difficult to have clear warnings. Figure 3 illustrates the current warning system for the MOST software.

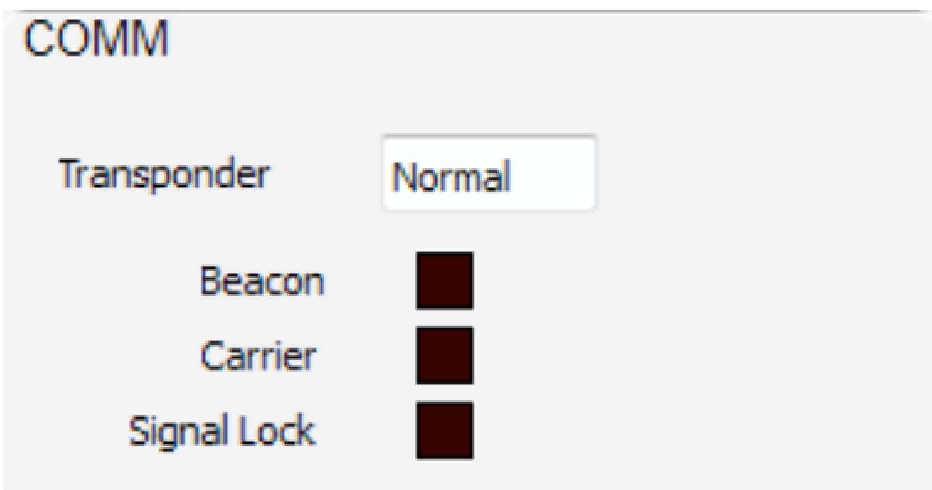


Figure 3. COMM warning widget [11]

When there is a warning, the corresponding square will light up red to identify. However, localized warnings are easy to miss and lack redundancy. Furthermore, the colors do not correspond to the severity level of the situation since red is the only option. In our design, we plan to improve this feature by assigning intuitive colors to different levels of warning messages.

Section IIb: Ground Control Station for Drones - Drone Engr

After looking into existing system displays for CubeSat mission control rooms, we found that most flight displays are integrated into the system display for a university-hosted mission [4, 10]. However, we wanted to gain insight into how an operator might interact with actual flight control, especially with flight displays available on the commercial market, so we investigated this flight display ground control system for a drone made and sold by Drone Engr [2]. We chose this drone flight system because it demonstrates how an operator can interact with a display, including sending commands in multiple ways and reading flight output.

Figure 4. Integrated flight and system display by Drone Engr.

The display features a visual readout display showing flight data and two types of camera footage alongside a flight icon demonstrating the current configuration of the drone's flight path. Quantitative flight data, such as speed, is presented on the left-hand side of the configuration. An operator controls the drone via the physical 3-axis joystick for yaw, pitch, and roll. The operator can additionally toggle on and off certain features with the lever-switches, such as switching the drone between different modes or toggling the ground control station between 'on' and 'off'.

Output is not only visual – the ground control station features noises and alarms in the case of a warning, for example. Finally, the user can also interact with the display by typing in commands with the keyboard or interacting with the touchscreen on the display.

Overall, this system offers significant versatility for user interaction with the system. Additionally, there exists a balance between human interaction and automation. A human operator makes the majority of the decision-making and uses manual control for adjusting pitch, yaw, roll, and speed. On the ground control system, there exists some level of automation that can help with decision-making: pan-tilt-zoom and stability control options assist a human handler and take some of the burden of manually controlling the system. However, an operator must know the activation steps (such as how to turn the system on and monitor the drone) and must be able to react to emergency situations quickly mid-flight. For this reason, a user of this ground control system would most likely need moderate training in order to use it effectively and safely.

Upon our analysis of the display, we saw some positive features that position this ground control system as an excellent option for a flight display. First, the ground control system had strong implementations of pictorial realism: features such as the flight icon accurately represented the drone's key features and could be recognized quickly in emergency situations. Additionally, the user interface is easy to interact with and redundant, allowing the operator to input commands in many different ways, including tactile input with a joystick or typing in keyboard commands. The company reported high user satisfaction with the user interface. Finally, the system used non-visual cues like audio, which can emphasize warning scenarios.

While there were many strengths of the system, we also identified some areas of improvement. First, the system displayed limited information – pictorial realism was prioritized at the expense of redundancy. In addition, the display focused on having a sleek, coherent look which led to some amount of discriminability. For example, the numerical readouts on the left-hand side, including speed, current, and remaining battery capacity, are easily confused and their colors do not correspond to a logical ordering of these outputs. Similarly, we found that the proximity compatibility principle was not followed well in some cases. For example, battery readout information on the left side is located far away from battery alerts that appear in the upper right hand corner. Lastly, we found that the flight display itself had limited predictive aiding, and observed that the system would benefit from predictive aiding tools to ease the workload on the drone operator during the flight scenario.

Figure 5. Close-up look at the flight display and control panel used by Drone Engr.

After analyzing the system, we identified some differences between the drone use case and the CubeSat use case. The drone requires a high level of user input, and the direction of the drone and pitch, yaw, and roll operations must be controlled during the duration of the flight. However, the CubeSat features less direct operator control, as an operator would instead send commands during an uplink or downlink window to interact with the CubeSat as opposed to controlling flight by a pitch-yaw-roll joystick. As such, not all aspects of this flight display are directly applicable to the cubesat display.

Section III: Designed System

For the testing phase of our design, an integrated flight and system display will be compared against a split two-monitor display. The primary components of our displays are a temperature gradient display, an overhead map showing the LIONESS' projected path, and a 3D live orientation display. Other essential components are a battery level indicator, signal strength indicator, and a display indicating current location and orientation coordinates. Commands would be input via a keyboard using pseudocode commands into a green command window. Our testing will also measure the effectiveness of typing in commands, which allows for versatile command input and choosing from a dropdown menu of commands, which may reduce the time needed to complete tasks.

The LIONESS display systems are meant to passively operate, even without human input, by maintaining the LIONESS in safe mode. In safe mode, the LIONESS' internal computer monitors location coordinates, orientation angles, and incoming spectrometry data. The computer can activate the LIONESS' reaction wheels to correct misalignment and avoid potential collisions. When needed, the user can switch the CubeSat to either experimental or charging mode, which allows them to manually input commands using a keyboard and mouse or touchscreen. Experimental and charging modes are mutually exclusive (i.e. when the LIONESS is charging its solar panels, it cannot collect spectrometry data and vice versa).

Section IIIa: Integrated Display

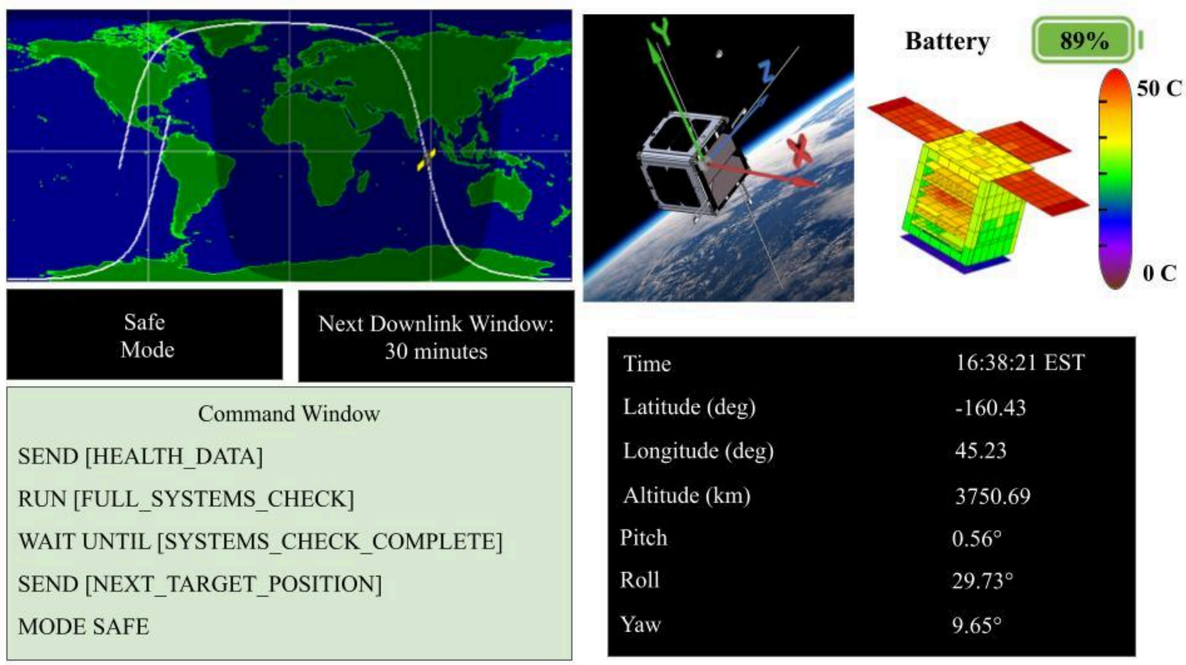


Figure 6. Integrated flight and system display.

Our integrated display prioritizes the most essential information needed for system control. A predictive aid map, LIONESS orientation simulator, essential location information, temperature gradient, command window, and upcoming downlink window countdown provide all the necessary data to maintain stable systems operation. Additionally, an integrated display reduces the information access cost of essential information and will potentially reduce the time a user needs to input commands.

With the integration of our displays, two visual displays complement the quantitative read-out of latitude, longitude, altitude, and angular orientation, implementing redundancy that will minimize user errors. The command window is the only place where a user can input commands and is differentiated from other display screens by its green hue. All passive display screens are black with white text, ensuring the legibility of key information on our display.

Despite minimizing information access cost, this integrated display cuts out less essential information, such as incoming spectrometry data and a countdown timer indicating the next experimental/charging window. Though these are not essential for operating the LIONESS, their exclusion limits user knowledge about the scientific objectives of the cubesat and may cause complications in the mission operations timeline.

Section IIIb: Split Display

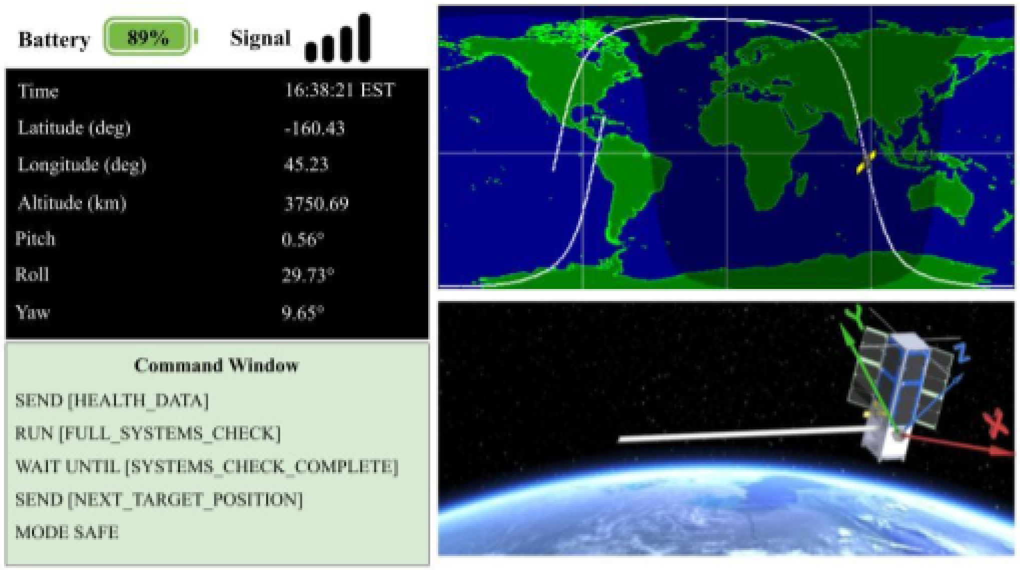


Figure 7. Individual single-monitor flight display and controls.

Figure 7 displays the flight system monitor of our split display, which prioritizes our predictive map and LIONESS orientation simulator. Essential system information (battery, signal strength, time-stamped location and orientation) is shown in the top right-hand corner. The green command window is included for proximity compatibility, as the user can see the live changes incurred by their commands. This setup also implements pictorial realism and redundancy; location information is displayed quantitatively and qualitatively.

Our system status display, shown in Figure 8, prioritizes non-essential flight information. Most notably, this setup includes incoming spectrometry data to inform the user about the status of scientific mission objectives. This is complemented by the displays showing when the next downlink and experimental/charging mode is (given that they are mutually exclusive). For instance, if there is no incoming spectrometry data and the LIONESS is in experimental mode, the system user will know immediately that a system failure has occurred. This same logic can be applied to signal strength in a downlink window. Hence, although a dual-monitor display increases information access cost, the additional information displayed can prevent possible operation errors.

Our team will weigh the benefits and drawbacks of both types of displays during our testing phase.

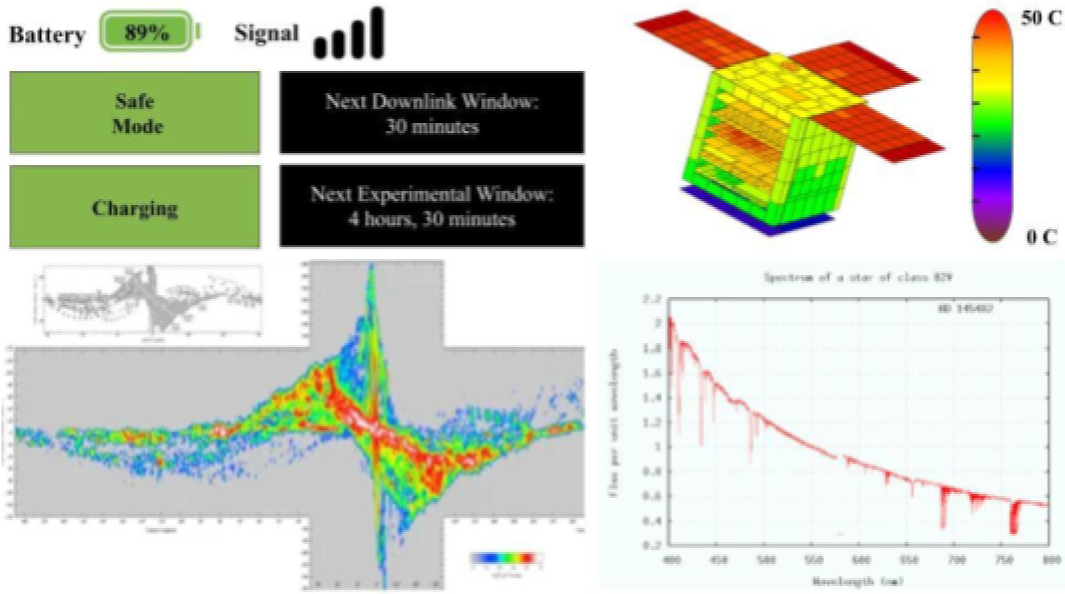


Figure 8. Individual single-monitor system status display.

Section IIIc: Warning Displays

A shared characteristic of our integrated and split-screen display is our caution/warning/emergency pop-up notifications. The hierarchy between warnings is as follows:

- Class 1 - Emergency - Red
  - Life threatening and time sensitive
- Class 2 - Warning - Orange
  - Time sensitive but not life-threatening
- Class 3 - Caution - Yellow
  - Not life-threatening or time-sensitive, but action still required

Each class has a unique tone and visual signal, which is accompanied by a short message summarizing the warning trigger. Possible triggers include low battery, unsafe temperatures, and disorientation. When an undesired event occurs, the visual pop-up and audio signal is activated, and the system automatically goes into safe mode. This allows the system to quickly diagnose and correct the issue. See Fig. 9 for an example of a possible warning event. Afterwards, the user has the ability to switch off from safe mode, restart all systems if necessary, and resume normal operations. Depending on the warning trigger, input commands can run diagnostic evaluations and determine if further action is needed to maintain proper operations.

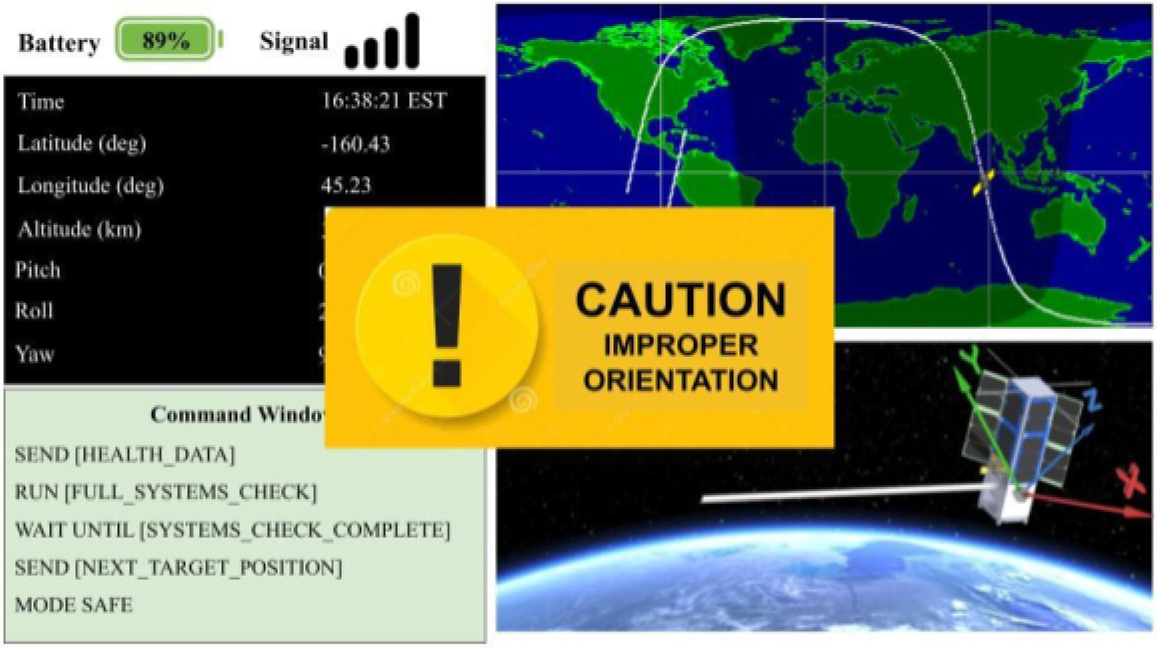


Figure 9. Caution pop-up on a single-monitor flight display.

Section IIId: Testing Display Alterations

Several changes were made to the displays for the testing phase. The most significant change was the command window. While typed-in pseudocode was kept for comparison, test subjects were also shown a dropdown command menu version of our display.

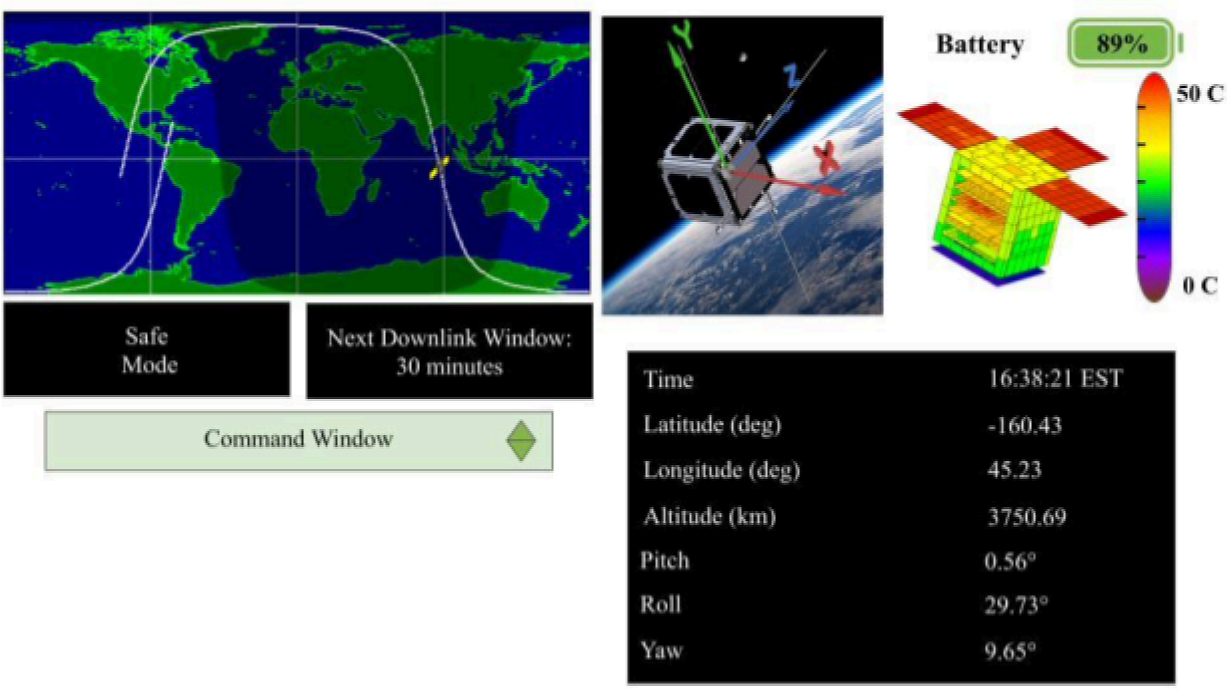


Fig. 10. Dropdown command menu iteration of integrated display.

Section IV: Testing Plan

Section IVa: Testing Objectives

The objective of testing is to determine the usefulness of an integrated as opposed to a separate display and the most efficient command inputting method. The integrated display combines the most essential information into one screen for easy access. However, there is value in separating system and flight displays to allow for more detailed information displays and clearer distinctions between usage modes. To assess the display format, we will split the testing participants into two groups: one testing the integrated display and the other testing the split display. Similarly, participants will either input commands using a drop-down on the touch screen or be required to type in commands to compare results from both input methods.

Section IVb: Hypothesis

The team hypothesizes that using an integrated display and touchscreen input for commands will reduce the user's workload while not decreasing the display's readability. Touch-screen displays tend to provide a more intuitive and user-friendly interface, but only when not a lot of text input is required [5]. Touchscreen interfaces are easier and quicker to use by a large range of users, which is ideal for a Cubesat team with a diverse range of technical backgrounds. Additionally, dropdown menus are easier to use when there is a limited number of possible inputs (~10). For the LIONESS, only a handful of commands are required, given that it is in orbit and requires very limited flight commands.

Section IVc: Evaluation Metrics

Various evaluation metrics were considered for this testing, such as the Bedford Workload Scale, the System Usability Scale, and the Cooper Harper scale. Based on the format of the testing and testing objectives, the Cooper Harper scale was selected as our main evaluation metric. In order to understand how the different display iterations impacted the users ability to monitor the satellite health and send commands, the modified Cooper Harper scale was the best option. We also plan to collect subjective feedback through informal questioning, making the System Usability Scale redundant.

The modified Cooper Harper scale [9] below prompts the subjective feedback of the participant into more organized categories that would allow for a final numerical rating. Using their responses, improvements may be made to the display design.

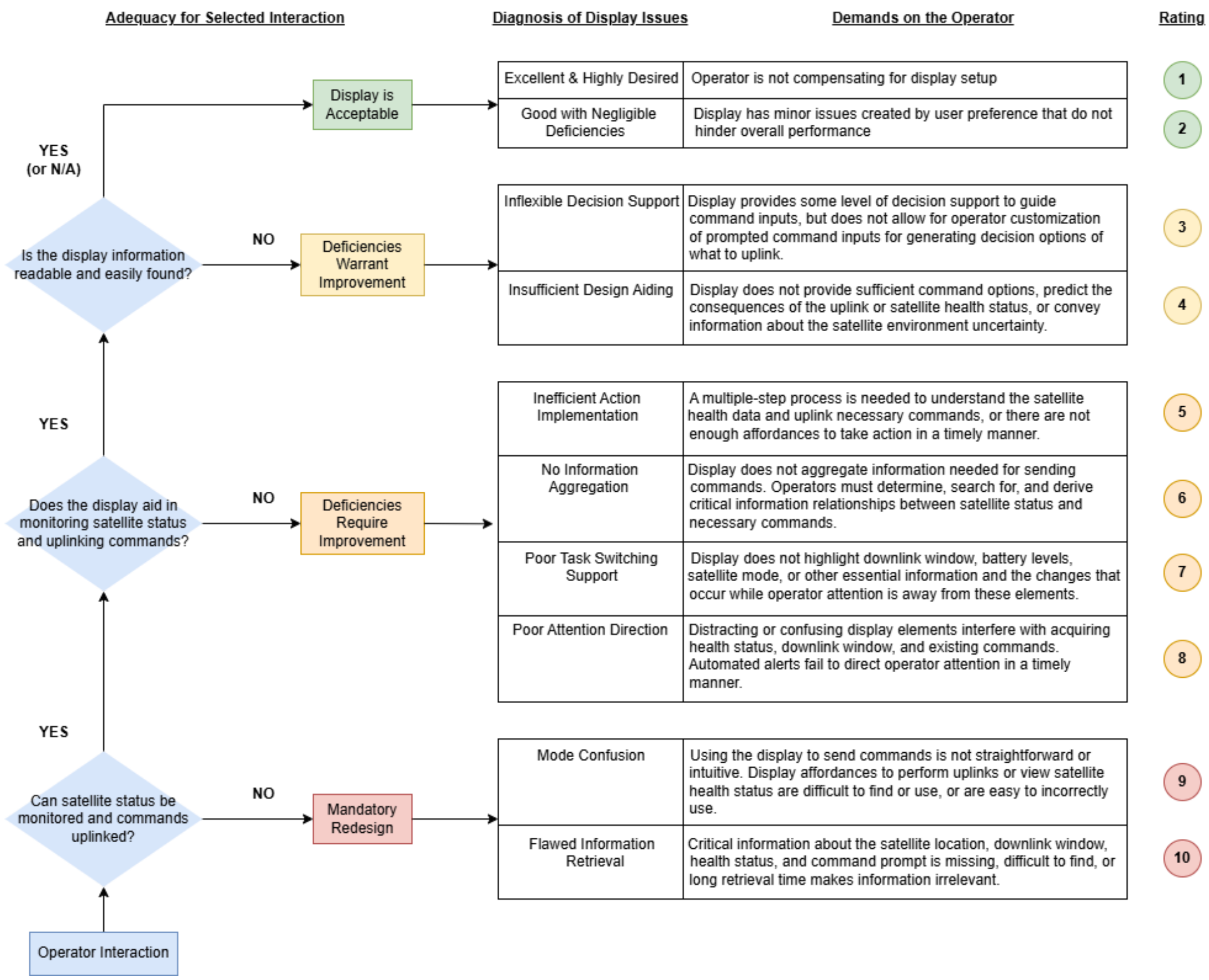


Figure 11. Modified Cooper-Harper scale for LIONESS operations.

Section IVd: Experimental Design

Participants for the testing were chosen based on their familiarity with CubeSats. It can be expected that the display users will be individuals who are at least decently familiar with CubeSats and the mission; to reflect this audience, chosen participants were all leads within the CubeSat team, to complete our display testing. Participants are all undergraduate or graduate students within the team within the Columbia Space Initiative. Since the testing utilizes four different varied parameters, we need at least four subjects to completely test our objectives. Each participant is only given one testing display iteration to reduce bias from having completed tasks on a similar display. We decided to test the displays between subjects instead of within subjects in order to reduce bias. While it was possible to vary which display was completed first between subjects, in order to keep the tasks consistent, we felt it was best for each subject to only test one display. There would have been much larger bias with certain secondary tasks which remain consistent across displays.

The testing requires about 15 minutes individually with each participant. Participants are given a touch screen and keyboard input display. Participants are then taken through a series of primary and secondary tasks which are commonly encountered during the mission duration. The table below presents the series of tasks given to the participants during the testing session. Secondary and primary tasks are alternated in order to keep the participant engaged and reflect a more realistic set of situations encountered during a CubeSat mission duration.

Situation	Task	Type
Satellite is in experiment mode	What is the battery level?	Secondary
Satellite is in experiment mode	When is the next downlink window?	Secondary
Satellite is in downlink window	Send health data	Primary
Low battery warning pops up; satellite automatically goes into safe mode	Restart all systems	Primary
Battery levels return to normal	Command satellite back into charging mode	Primary
Satellite is in downlink window	What is the latitude?	Secondary
Satellite is in charging window	What is the longitude rate of change?	Secondary

Table 1. Primary and secondary tasks for testing phase.

Subjects are first provided with a brief overview of the display purpose, the location of various components on the screen, and the command input method. They are also told the process in which a warning may be addressed. This walkthrough reflects the basic information that may be assumed of any user of this display while leaving out specific details about the tasks to be asked to maintain the role of the display in helping the user through the tasks. This sweet spot also allows us to accurately judge the workload on the user.

Subjects given the keyboard input displays were provided with a dual screen setup. A larger desktop functioned as the display while a small laptop in front allowed the user to type in commands. After being provided with the brief summary of the display, subjects with the typed pseudocode input were given a paper with the pseudocode commands and their descriptions listed. They were given a moment to familiarize themselves with these commands as may be expected of the display user.

Subjects provided the touch screen input display were given a tablet where they interfaced with the display, clicking on a toggle to view and send commands. Regardless of the display used, all participants were asked to complete the same tasks outlined in Table 1. Participants answered questions out loud. After each question was asked, a moderator started a stop watch and stopped it when the participant finished correctly answering the question or carrying out the task. The moderator also recorded any mistakes noticed by participants to understand common mistakes or misunderstandings during testing.

After successfully completing the tasks, the subject is asked to fill out the modified Cooper Harper scale for a structured understanding of the workload on the user. At the very end, the participant is asked for subjective feedback on the experience. The subject was prompted for subjective feedback through the following three questions which prioritized our testing goals:

1. Would you prefer an integrated or separate screen display?
2. Would you prefer a touch screen or a keyboard and mouse?
3. Would you prefer drop-down over typed commands?

The user was also asked for general feedback on what they liked, disliked and anything else not captured in these questions. Including the walkthrough, tasks, and feedback portions, the testing took 10-15 minutes per participant.

Section V: Experimental Results

Section Va: Qualitative Data Analysis

Participants' responses to the subjective questions are listed in Table 2.

Subject	Question	Response
1 - integrated display with drop-down command input	What did you like about the display?	“I liked that everything was available and easy to see at a glance. Text was big, and things were clear - should be good from the operator's point of view”.
	What aspects of the display could be improved?	“Completely might be my preference, maybe having lots of flashing colors everywhere might not be the best in the end, but some additional feedback when the modes switched could be nice.
	Would you prefer an integrated or separate screen display?	“Integrated, it was intuitive”
	Would you prefer a touch screen or a keyboard and mouse?	“Touch screen, it’s faster”
	Would you prefer drop-down over typed commands?	“Yes, the drop down was super clear”

	Other feedback?	“Have some alert when something has changed”
2 - separated display with tying command input	What did you like about the display?	“Top left: info easy to understand, battery, signal, etc.” “Flight display looks clean”
	What aspects of the display could be improved?	“Most of the confusion comes from sending commands, find a better way to send commands” “Certain Aspects not labeled” “Focus on the display of what the returned data looks like”
	Would you prefer an integrated or separate screen display?	“Integrated would be easier, so I wouldn’t need to be clicking around as much”
	Would you prefer a touch screen or a keyboard and mouse?	“Touch screen would be better, although in general, typing can be nicer than clicking”
	Would you prefer drop-down over typed commands?	“Yes, but I would still prefer a keyboard and a mouse to interact with the system”
	Other feedback?	“its the commands that confused me.” "I enjoy typing more than clicking, but pseudo code would need to be shortened."
3 - integrated display with tying command input	What did you like about the display?	“The information for the systems was well-displayed and easy to read and understand. The command prompts that needed to be typed allowed for robust use of the system”
	What aspects of the display could be improved?	“The downlink window display needs some work because I could not tell that there was an active downlink happening”
	Would you prefer an integrated or separate screen display?	“Yes, I liked having everything in one place”

	Would you prefer a touch screen or a keyboard and mouse?	“Touch screen would be better”
	Would you prefer drop-down over typed commands	“Yes, drop-down would be faster”
	Other feedback?	N/A
4 - separated display with drop-down command input	What did you like about the display?	“The display was very intuitive and easy to use. I had no trouble navigating it.”
	What aspects of the display could be improved?	“There is nothing that could be improved.”
	Would you prefer an integrated or separate screen display?	“I think both are good. But if I had two monitors, I would prefer separated.”
	Would you prefer a touch screen or a keyboard and mouse?	“Touch screen”
	Would you prefer drop-down over typed commands	“Yes, I liked the drop-down”
	Other feedback?	N/A

Table 2. Participant Subjective Feedback

The participant's feedback illustrates that they liked the clarity of the design as it was easy to read, and finding relevant information was intuitive for all command input methods and separated vs. integrated. However, participants highlighted several areas for improvement. For example, the display needed an enhanced feedback mechanism to provide visual cues when the CubeSat mode switches or the downlink window changes. The current display only had the text switch, so having a color associated with the different modes would aid in the user identifying changes quickly. Furthermore, the participants who tested the typing input commands suggested a more robust system with shorter pseudo-codes to allow an easier flow for command input. Lastly, a participant noted that the display should include better labeling for return data so the user knows how to interpret the data.

All four participants preferred the drop-down input menu method over typed commands since it reduced their workload. Three participants preferred a touchscreen interaction, while one stated they preferred a keyboard and mouse to interact with the display. Three out of four participants preferred an integrated display, while one commented they would like a separate display with dual monitors.

Section Vb: Cooper-Harper Rating Analysis

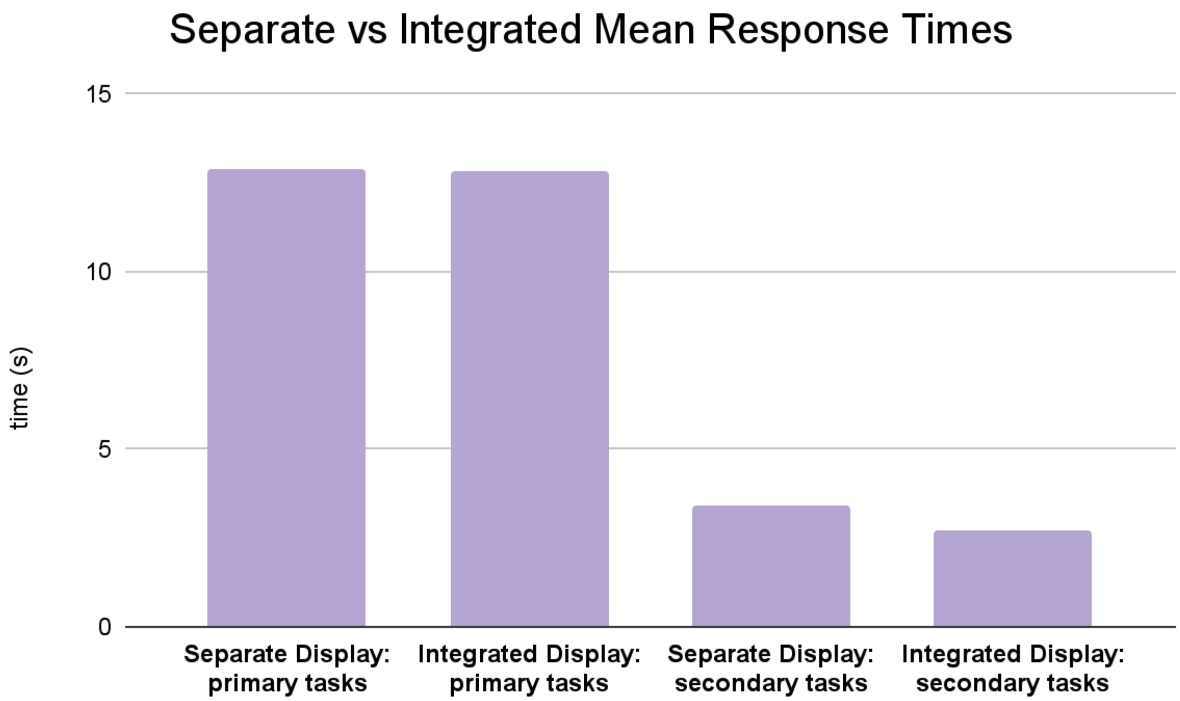
For the Cooper Harper feedback, three participants rated the display a 2, indicating it had minor issues created by user preference that did not hinder overall performance. The minor issues were gathered during the subjective feedback section above. While one participant rated the display a 1, they believed as an operator, they were not compensating for the display setup. This participant had a separate display with drop-down commands. The feedback from the Cooper Harper ratings indicates that our designs were all sufficient, which led to further investigation on which design was best with analysis of qualitative feedback and timing results.

Section Vc: Task Response Time Analysis

The task response analysis was conducted again following feedback from the final presentation. In this round of analysis, a new focus was placed on identifying response times with the participants' input and display type for clearer visualization. The rework of this analysis revealed some errors in the previous calculations, presenting clearer results for the CubeSat display.

The response times for each participant, classified as the duration between being asked a question and completing the desired response, were measured. The data organization consisted of a task-type analysis, where the response times between the primary and secondary tasks were compared across participants to determine which display and input method was the most efficient. A person performance analysis, where the response times for each participant were compared to search for outliers and consistency.This involved averaging the response times of the two participants who used the integrated and separate. The statistical methods used in this analysis were mean, standard deviation, minimum, and maximum.

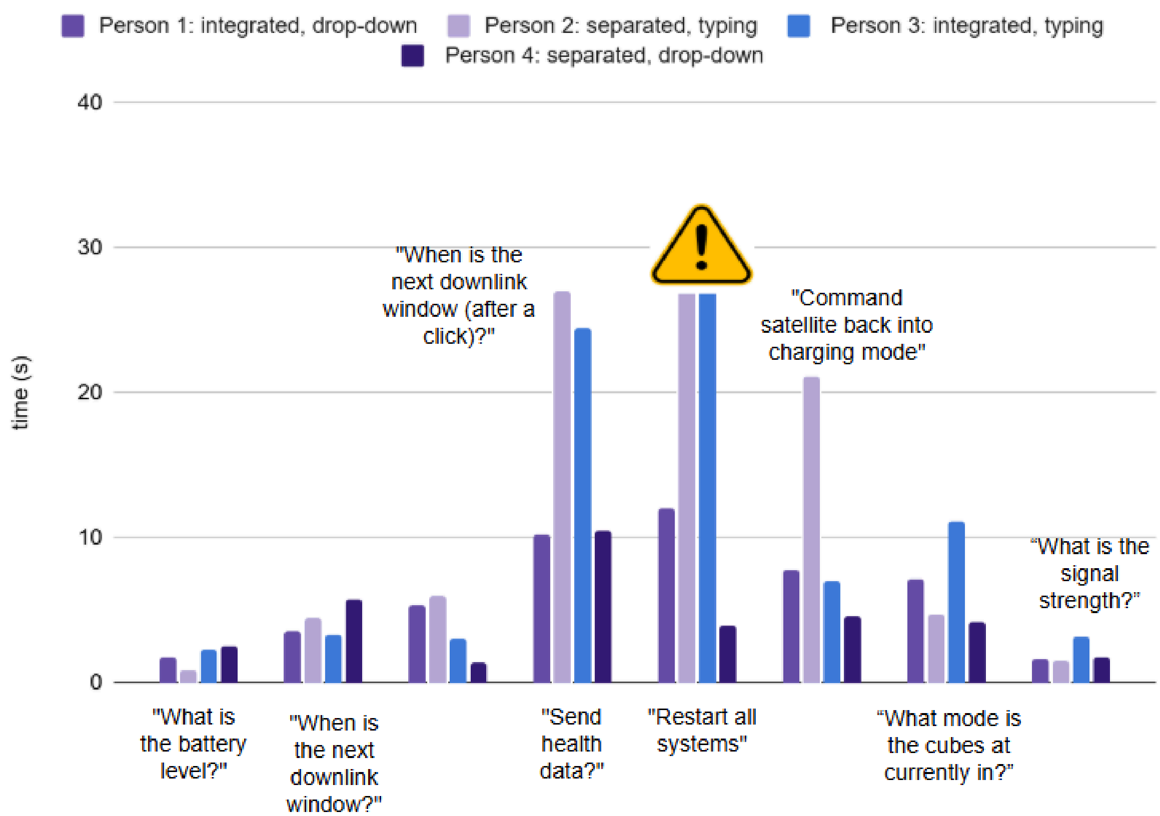
- **Task Type:**
  Graph 1 depicts the average response times split into primary and secondary tasks of the participants who had integrated and separate displays.



Graph 1: Mean response times for primary and secondary tasks comparing separated and integrated displays

The separate and integrated displays were almost identical across both secondary and primary tasks, illustrating consistent information throughout the designs. The small difference seen between integrated and separate displays for secondary tasks can be attributed to the participants needing to switch between screens with the separated display.

- **Person Performance:**
  Graph 2 compares participants' response times corresponding to their input method, typing or drop-down, and their display, integrated or separate. The caution symbol indicates that a warning symbol appeared on the display before the question was asked. Our goal for giving each participant a different input method and display was to collect a wide range of feedback and remove bias as a participant became familiar with the display. However, in future testing, our experimental design would have each participant test two input methods with their display for individual comparison.



Graph 2: Mean response times of participants for all tasks

In Graph 2, participants who used a drop-down input method had a significantly shorter response time for primary tasks (i.e., "send health data") than those who used a typing input method. This illustrates that a drop-down command input is more efficient as it reduces an operator's workload. However, qualitative feedback shows that some participants did prefer typing as it offered greater flexibility. In addition, participants who used typing commands took longer to respond to emergencies, which could result in CubeSat damage. Furthermore, person one, who had an integrated drop-down system, and person two, who had a separated drop-down, had very similar times throughout the experiment, illustrating that **the main slowdown in user interaction is the input method, not the display method.** Despite this, the qualitative feedback revealed that most participants preferred the integrated display over the separated display.

Section VI: Limitations

There were several limitations for the testing of our displays. Perhaps the largest limiting factor from obtaining robust results in the study is that we used a small sample size. For the experiment, we had two people testing the integrated display and two people testing the separate displays. Each set of test subjects tested both the methods of user input. However, our test subjects had a variety of feedback and ratings, for which it is difficult to understand whether any of our users were outliers with a small sample size. For example, one of our test subjects said "there is nothing that could be improved" while our other subjects had more extensive feedback about the system. Testing a larger number of subjects would not only improve our metrics to better reflect the user population, but would also allow us to receive a larger amount of subjective feedback upon which to iterate our design.

Another issue is that because each participant tested two input styles, there may have been a learning bias in the results. Although the user input styles were different, some of the features of the display (such as the battery life and signal strength alert) were similar. The test subject could improve their reaction time when using a similar display for the second time. While we implemented randomization of the order of tests for students, in the future we could attempt to account for the amount of improvement that subjects experience on their second test. Additionally, we could include a control group that only tests one version of the display and input in order to account for the benefits that the repeated test subjects might experience and control for the bias.

Furthermore, we were not able to control for every parameter of the study. For example, workload can be biased because of varying levels of familiarity with CubeSats present in the participants. In the future, we could provide everyone with a base level of training before the experiment to attempt to control this parameter. Additionally, we conducted the test in a computer lab which could have had varying levels of distraction as some other students were moving in and out of the space as testing was occurring. Future versions of the test should take place in a designated, quiet location to ensure a distraction-free environment.

Only one formal metric was utilized to gather subjective feedback from the participant. While this was very valuable, it also leaves out feedback that may be acquired from other metrics mentioned within the Evaluation Metrics section. We also provided an informal feedback form for students to answer some questions about what they liked and what they thought could be improved. Given more time, however, various metrics may be utilized for a more thorough analysis. Additionally, since the feedback form was not anonymous, test subjects may have felt pressure to provide a positive review which could have skewed the data. In the future, we could create a fully anonymous survey that would let students feel comfortable to give all of their feedback.

Finally, due to time constraints, there were many additional variables that would benefit from a formal test. We focused mainly on the style of display and the command input type. However, future tests could focus on proximity compatibility of emergency alerts, which are important functions of the display layout. The ideal workflow would include a robust test of one display, then iterating on that display based on the results, then conducting another robust test of the improved display. For the scope of the project, we were only able to test one iteration of the design. Future iterations are left to the members of the Columbia Space Initiative CubeSat team, so that they may be able to finalize a display that can be used in a future Mission Control room.

Section VII. Future Recommendations

Based on the feedback received from our test subjects, the integrated version of our display was preferred over separate flight and system displays. Additionally, a drop-down menu of commands was preferred over typed-in pseudocode. In terms of the hardware used to control our displays, testing participants preferred a touch screen tablet over a keyboard and mouse setup.

Aside from these overarching changes, participants also recommended having more clearly labeled downlinking/experimental windows that gave an alert whenever they switched. In the separate display, the modes were formatted so that the current mode was highlighted in green while those that were inactive were greyed out. Since this feedback was provided by participants using the integrated display, using the mode display from the separate display and adding it to the integrated display would solve this issue. Along with this, an automated voice telling the user when the mode has been changed would be helpful especially if the user is not looking at the screen.

Another concern with the integrated display was that it was difficult to understand when a downlink was taking place. Incorporating a flashing symbol behind the text “Downlink” would clarify when a downlink is taking place.

Additionally, in the case of our split display, participants were slightly confused by the status of incoming data and reported that there should be a more clear indicator of the status of returned spectrography data. Since the nature of the returned data for CSI’s actual CubeSat mission is unclear, clarifying this and including more qualitative aspects of the incoming data within the display may resolve this concern. For example, incorporating a summarization window displaying the status of incoming data (in addition to the graphs) would help the user intuitively and quickly determine how the CubeSat is performing.

These changes would also require a secondary testing phase using different members of the Columbia Space Initiative’s CubeSat mission. This testing phase would require a scaled up setup with a larger touch screen tablet in order to closely simulate its possible usability. As the display develops, the Columbia Space Initiative will gain knowledge on how to create replicable and useful testing plans.

Section VIII: Conclusion

The proposed CubeSat mission control display is a novel design that will enable university CubeSat teams, such as the Columbia Space Initiative, to monitor and communicate with a CubeSat following launch.

To understand existing designs for related use-cases, we investigated a space systems mission operations display developed by the University of Hawaii at Manoa Space Flight Laboratory [] and a commercial drone flight display developed and sold by Drone Engr [2]. Our analysis of these displays led us to prioritize several design principles in our CubeSat display, including pictorial realism, proximity compatibility, legibility, and low information access cost. Additionally, we determined that it was necessary to design our display around the specific use-case of the CubeSat mission, which involves communicating with the CubeSat during uplink/downlink windows and monitoring flight path and system data. Our proposed display showcases flight data and system information in an easy-to-use integrated display. Users can interact with the CubeSat during an uplink-downlink window by inputting pseudocode commands.

Currently, we have proposed a testing setup in which we evaluate the effectiveness of the pseudocode command input as well as the effectiveness of the integrated vs. separate displays. A modified Cooper Harper scale will be utilized to evaluate workload, readability, and user satisfaction. Additionally, subjective feedback will be asked to each participant at the end of the study via a short on-paper questionnaire, including questions such as “What did you like about the display?” and “How do you think the display could be improved?”

The data from the testing session will be used to lay out a path of improvement for the proposed display. Eventually, this display will form the basis of the Columbia Space Initiative CubeSat Mission Control Room. Currently, the CSI CubeSat team is developing a ground station to be built on or near Columbia’s campus. Once this is established, students will be able to collect data from incoming satellites including the club’s very own mission set to launch late next year. Monitoring this data and interacting with the satellite will be crucial. Future work will focus on best understanding how the display can serve the CubeSat Mission operators and how to integrate the display into the Columbia Space Initiative’s mission operations.

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