Astro Girls

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CubeSat Display Overview

Goal: *Design a CubeSat System & Flight Display that could be used by Columbia Space Initiative CubeSat Operators in a Mission Control Room.*

Design principles followed:

<u>System</u>

- Replace memory with high amount of information
- Implement pictorial realism
- Limit discriminability
- Lower the information access cost
- Easy to interact with, send/receive commands

<u>Flight</u>

- Emphasize proximity Compatibility
- Implement Pictorial Realism
- Include redundancy
- Utilize predictive aiding

Changes since Preliminary Design
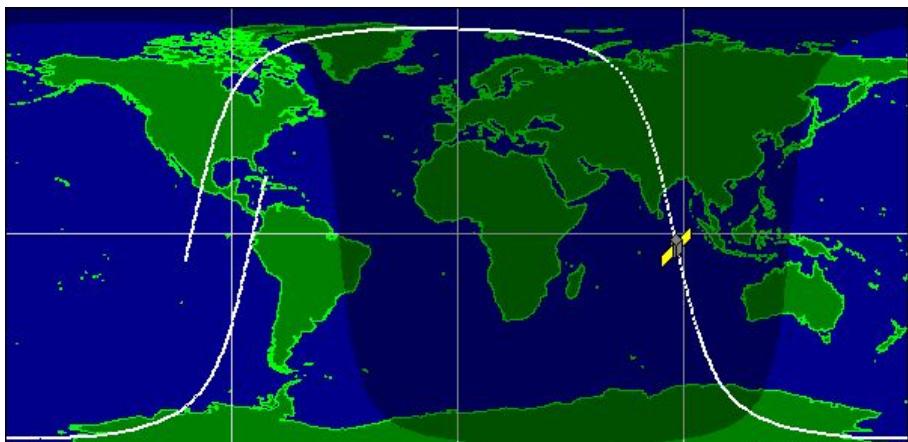
- We redesigned to include both *Integrated* & *Separate* displays (as opposed to just combined displays)

- We included *typed commands* and *dropdown menus* for two user input options

Goal: *Create a display which best enables a CubeSat operator to efficiently and effectively interact with the satellite during uplink/downlink windows and understand the current state of the system.*
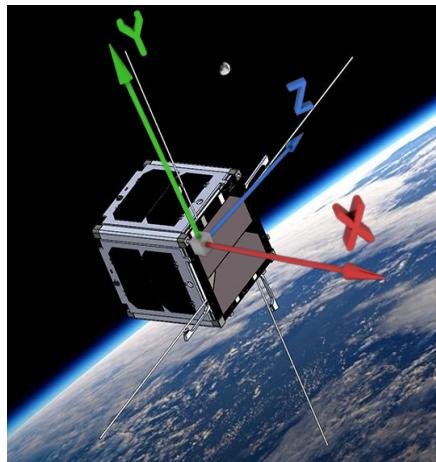
Integrated Display

## with a drop down menu
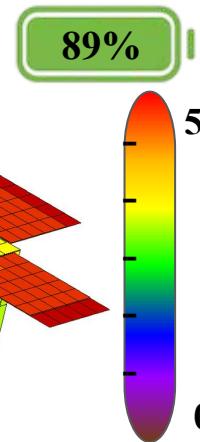
Safe
Mode

Next Downlink Window:
NOW

Battery 89%

50 C

0 C

Command Window	

RUN [FULL_SYSTEMS_CHECK]

MODE SAFE

MODE CHARGING

SEND [HEALTH_DATA]

Time	16:38:21 EST
Latitude (deg)	-160.43
Longitude (deg)	45.23
Altitude (km)	3750.69
Pitch	0.56°
Roll	29.73°
Yaw	9.65°

Battery 89%

50 C

0 C

Safe
Mode

N...

CAUTION
IMPROPER
ORIENTATION

Command Wi...

RUN [FULL_SYSTEMS_CHECK]

MODE SAFE

RESTART ALL SYSTEMS

SEND [HEALTH_DATA]

16:38:21 EST

-160.43

45.23

Altitude (km)   3750.69

Pitch   0.56°

Roll   29.73°
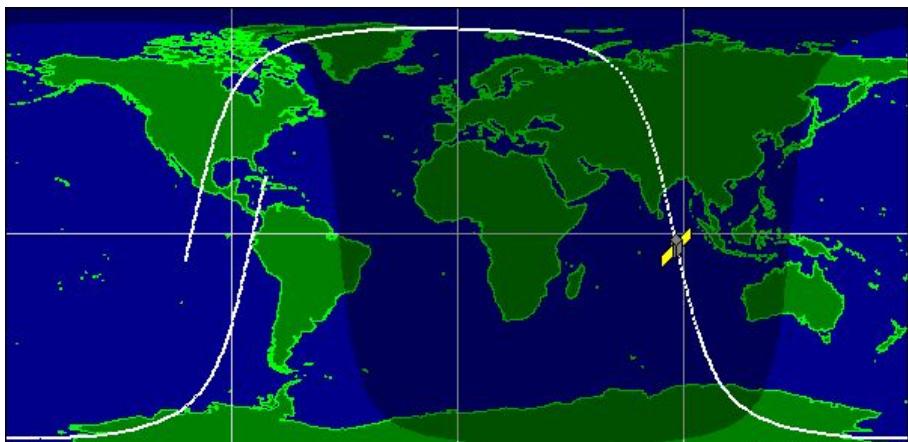
Yaw   9.65°

Integrated Display
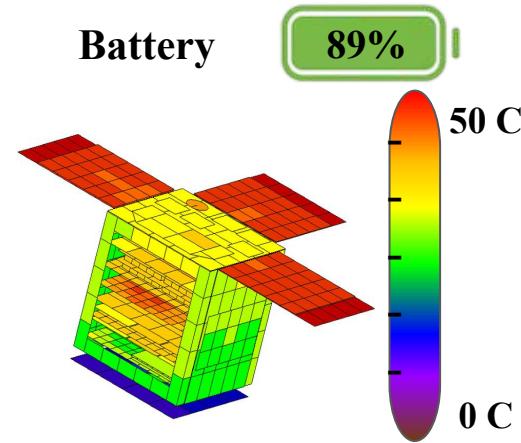
with typed commands

Battery 89%

50 C

0 C

Safe
Mode

Next Downlink Window:
30 minutes

Command Window

SEND [HEALTH_DATA]

RUN [FULL_SYSTEMS_CHECK]

WAIT UNTIL [SYSTEMS_CHECK_COMPLETE]

SEND [NEXT_TARGET_POSITION]

MODE SAFE

Time	16:38:21 EST
Latitude (deg)	-160.43
Longitude (deg)	45.23
Altitude (km)	3750.69
Pitch	0.56°
Roll	29.73°
Yaw	9.65°
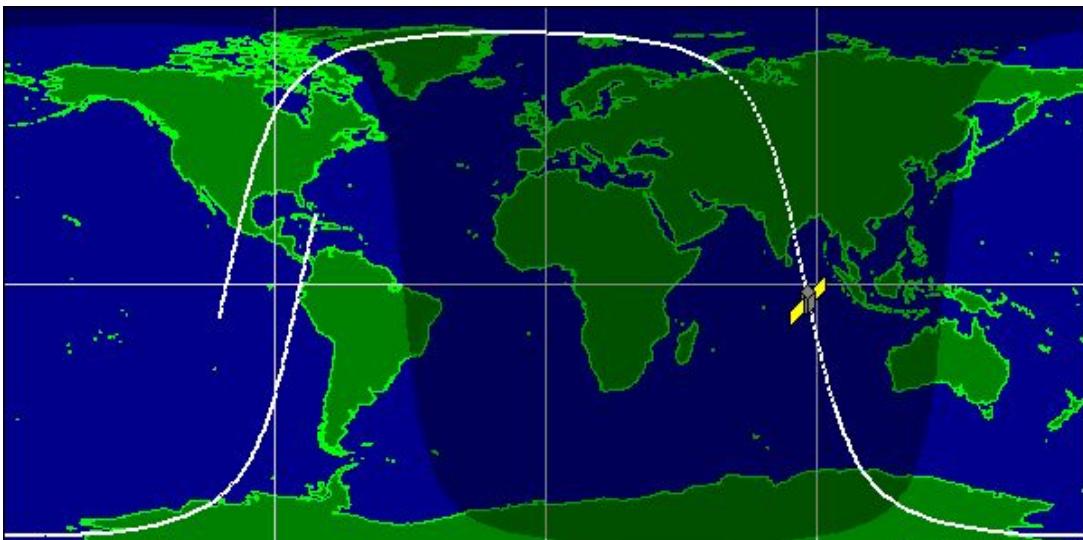
Separated Display

with dropdown menu

Time	16:38:21 EST
Latitude (deg)	-160.43
Longitude (deg)	45.23
Altitude (km)	3750.69
Pitch	0.56°
Roll	29.73°
Yaw	9.65°

Command Window

RUN [FULL_SYSTEMS_CHECK]

MODE SAFE

MODE CHARGING

SEND [HEALTH_DATA]

Safe Mode	Next Downlink Window: 30 minutes
Charging	Next Experimental Window: 4 hours, 30 minutes

50 C

0 C

Spectrum of a star of class B2V

HD 145482

Flux per unit wavelength

2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

400 450 500 550 600 650 700 750

Wavelength (nm)
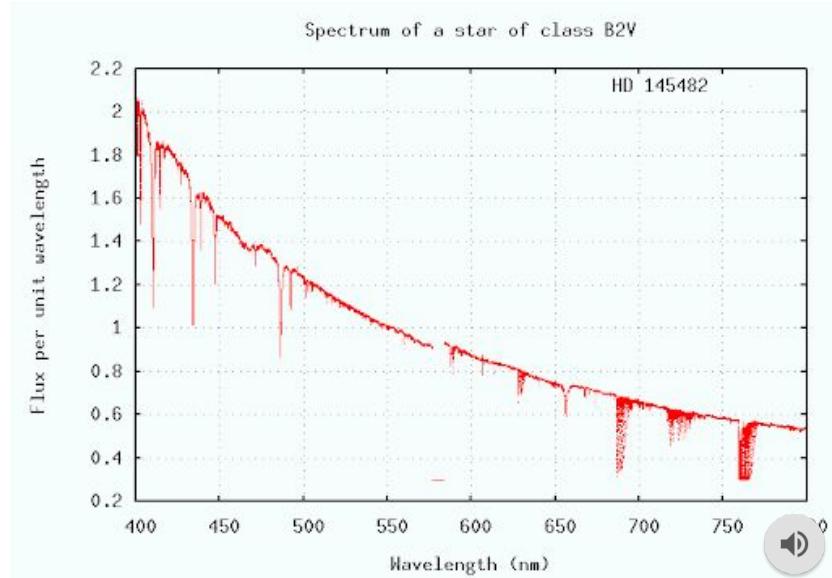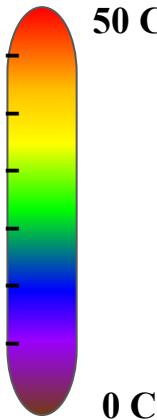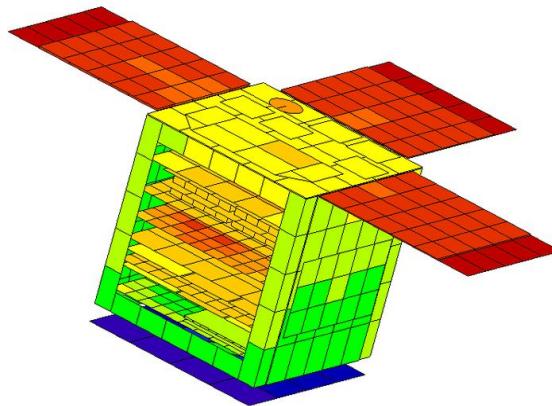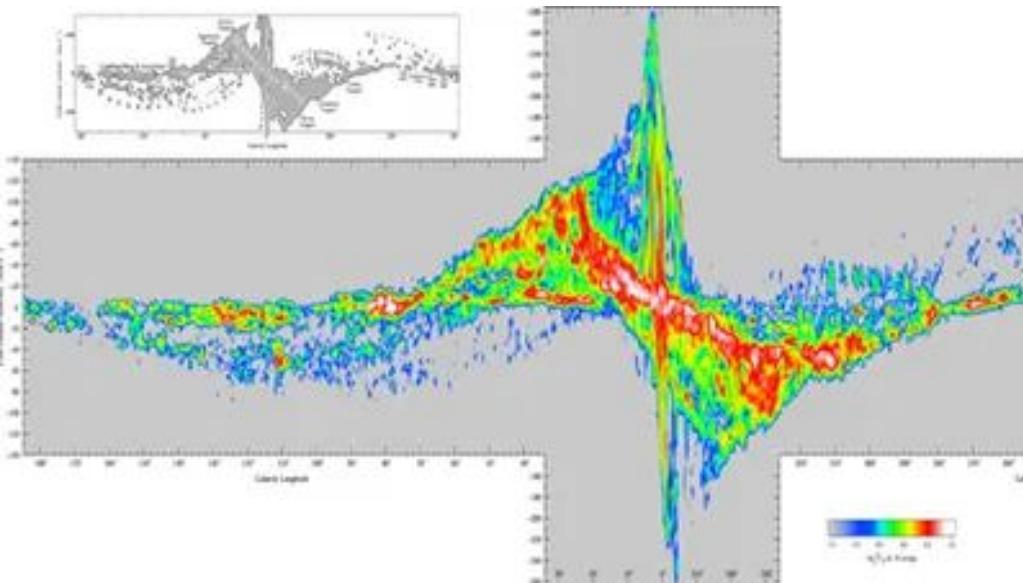
Separated Display

with typed commands

Battery	**89%** **Signal**

|	
Time	16:38:21 EST
Latitude (deg)	-160.43
Longitude (deg)	45.23
Altitude (km)	3750.69
Pitch	0.56°
Roll	29.73°
Yaw	9.65°

Command Window

SEND [HEALTH_DATA]

RUN [FULL_SYSTEMS_CHECK]

WAIT UNTIL [SYSTEMS_CHECK_COMPLETE]

SEND [NEXT_TARGET_POSITION]

MODE SAFE

Battery 89%   **Signal**
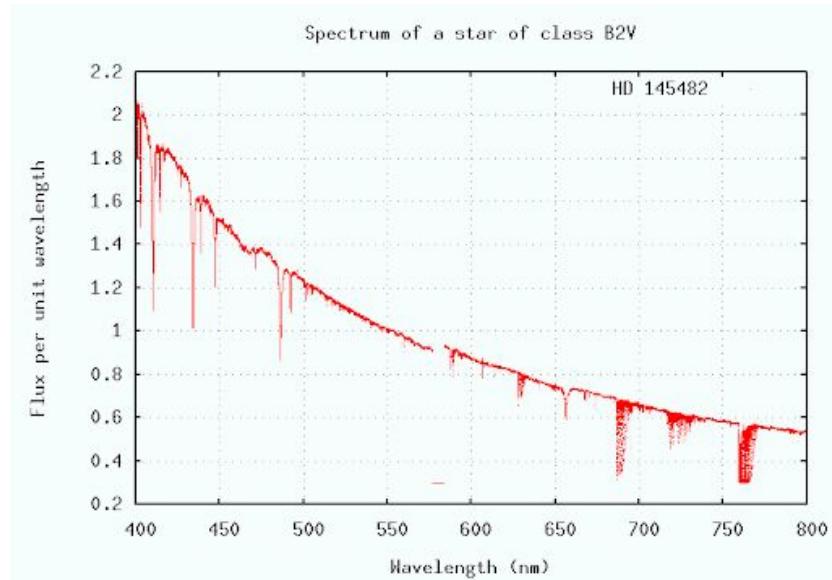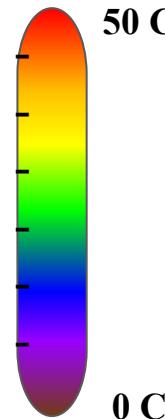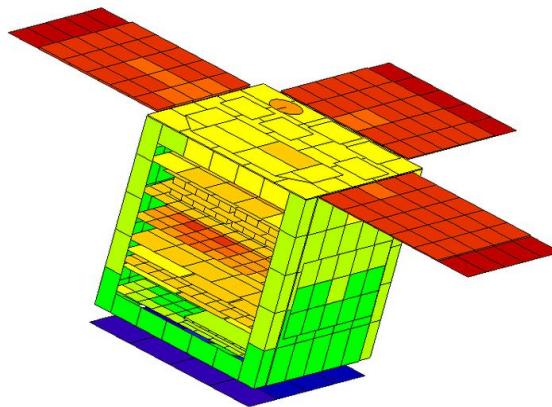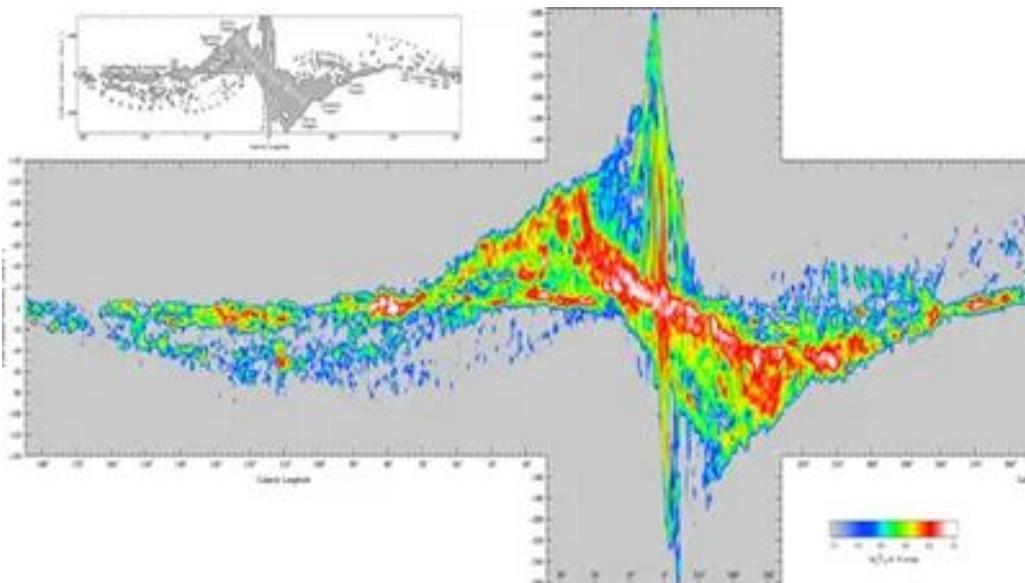
| Safe Mode | Next Downlink Window: 30 minutes |
| Charging | Next Experimental Window: 4 hours, 30 minutes |

50 C

0 C

Spectrum of a star of class B2V

HD 145482

Flux per unit wavelength

Wavelength (nm)

Experiment

Hypothesis

Experimental Hypothesis: An integrated display and touchscreen for commands will reduce the user's workload while not decreasing the display's readability and usability.

- **Bases for Hypothesis:** Integrated displays have a high readability and touchscreen commands are more easily inputted than keyboard commands.

Experimental Metrics

1. Cooper Harper Scale: used to collect and organize quantitative feedback from participants

2. Subjective Feedback: used to explain the number ranking and provide detailed feedback

3. Task response time: time it takes a participant to complete a task

Participants familiarity with CubeSats varies

Quantitative data - numerical ranking and time
Qualitative data - informal feedback

Cooper-Harper Scale

| Adequacy for Selected Interaction	Diagnosis of Display Issues	Demands on the Operator	Rating
Display is Acceptable	Excellent & Highly Desired	Operator is not compensating for display setup	1
	Good with Negligible Deficiencies	Display has minor issues created by user preference that do not hinder overall performance	2
Deficiencies Warrant Improvement	Inflexible Decision Support	Display provides some level of decision support to guide command inputs, but does not allow for operator customization of prompted command inputs for generating decision options of what to uplink.	3
	Insufficient Design Aiding	Display does not provide sufficient command options, predict the consequences of the uplink or satellite health status, or convey information about the satellite environment uncertainty.	4
Deficiencies Require Improvement	Inefficient Action Implementation	A multiple-step process is needed to understand the satellite health data and uplink necessary commands, or there are not enough affordances to take action in a timely manner.	5
	No Information Aggregation	Display does not aggregate information needed for sending commands. Operators must determine, search for, and derive critical information relationships between satellite status and necessary commands.	6
	Poor Task Switching Support	Display does not highlight downlink window, battery levels, satellite mode, or other essential information and the changes that occur while operator attention is away from these elements.	7
	Poor Attention Direction	Distracting or confusing display elements interfere with acquiring health status, downlink window, and existing commands. Automated alerts fail to direct operator attention in a timely manner.	8
Mandatory Redesign	Mode Confusion	Using the display to send commands is not straightforward or intuitive. Display affordances to perform uplinks or view satellite health status are difficult to find or use, or are easy to incorrectly use.	9
	Flawed Information Retrieval	Critical information about the satellite location, downlink window, health status, and command prompt is missing, difficult to find, or long retrieval time makes information irrelevant.	10

Flowchart:

Operator Interaction →
Can satellite status be monitored and commands uplinked?
- NO → Mandatory Redesign
- YES ↑

Is the display information readable and easily found?
- NO → Deficiencies Require Improvement
- YES ↑

Is the display satisfactory without improvement?
- NO → Deficiencies Warrant Improvement
- YES (or N/A) → Display is Acceptable

Subjective Feedback

1. What did you like about the display?

2. What aspects of the display could be improved?

3. Do you have any other feedback?

Experimental Design

Subjects

- 4 subjects from the Columbia Space Initiative CubeSat team

Procedure

- Participants were randomly given variations of the integrated, separated, drop down, and typed command displays
- Participants were asked to complete a series of primary and secondary tasks
- A team member timed and recorded each task
- Once completed, participants completed the Cooper Harper scale, and were prompted for subjective feedback
- Each interview lasted approximately 10-15 minutes

Tasks

Primary
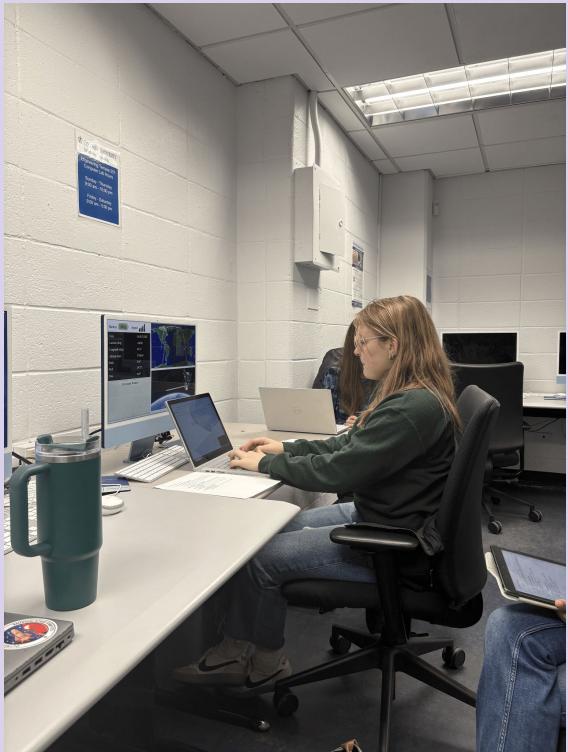
- Command the satellite to send health data
- Restart all systems
- Command the satellite into charging mode

Secondary
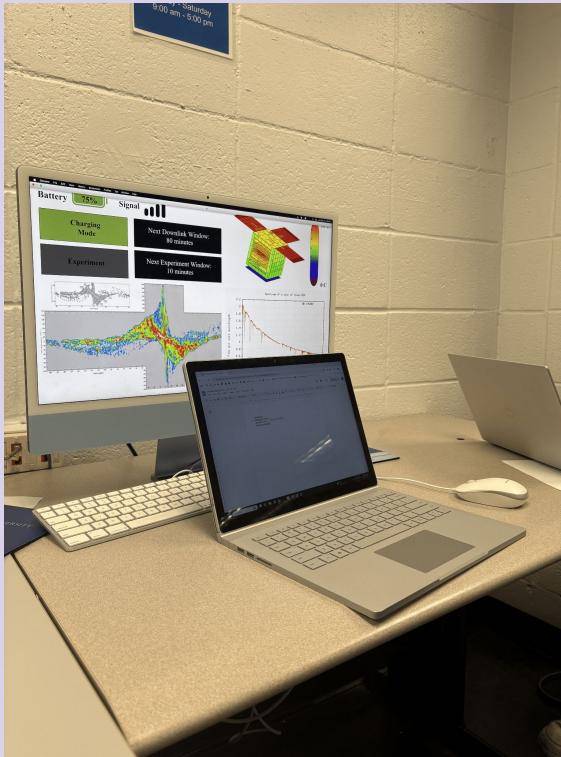
- What is the battery level?
- When is the next downlink window?
- What is the CubeSat latitude?
- What mode is the CubeSat currently in?

Limitations

- Small sample size of 4 participants is not statistically significant
- Assumes the user of the display will be very familiar with CubeSats
- The typed commands input could not be accurately simulated
- The display size used in testing is not indicative of real displays
- Because of the short time scales recorded per task, there is greater room for error
- The visuals are not entirely accurate to the graphs or diagram of the CubeSat to be monitored

CSI President testing our displays.
(photo used with consent)
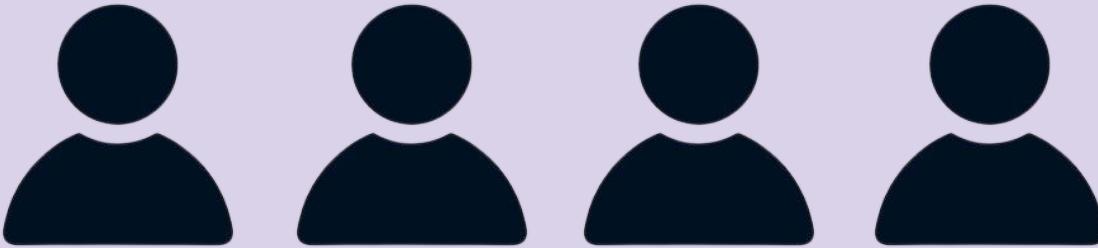
Typed command display
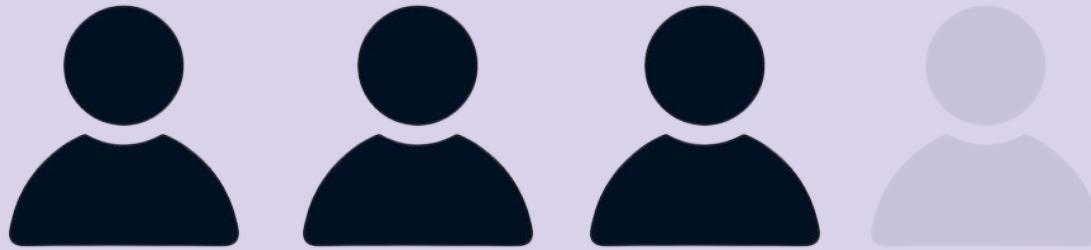
Touch screen input display

Experimental Results

- 4/4 participants preferred dropdown menu over typed commands

Experimental Results

- 4/4 participants preferred dropdown menu over typed commands
- ¾ Participants preferred a touchscreen over a keyboard and mouse
- ¾ participants preferred an integrated display

Qualitative Data - Subjective Feedback

"I like how not overwhelming it is with different data."

"I want more focus on the display of what the returned data looks like."

"Touch screen would be better."
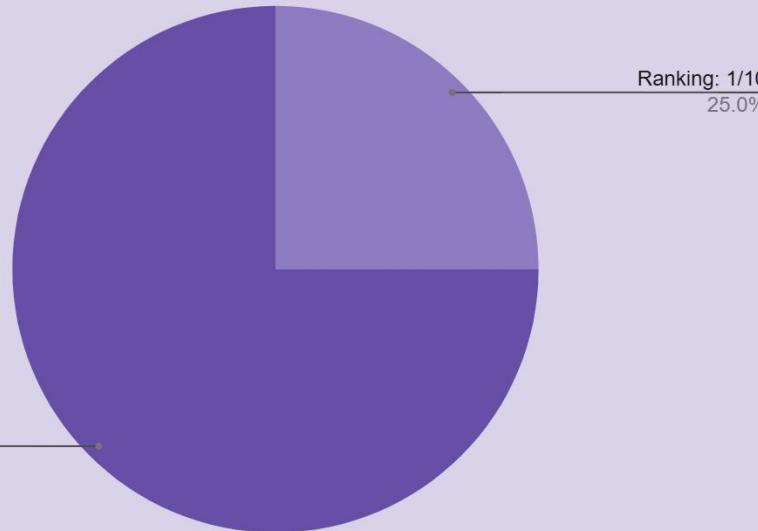
"The downlink window display needs some work because I could not tell that there was an active downlink happening."

"I would tweak the warning system to alert an operator that the change occurred."

"It's the commands that confused me"

Quantitative Data

Cooper Harper Results

Ranking: 1/10
25.0%

Ranking: 2/10
75.0%

| Excellent & Highly Desired | Operator is not compensating for display setup | 1 |
| Good with Negligible Deficiencies | Display has minor issues created by user preference that do not hinder overall performance | 2 |

Response Time Data Analysis

Statical Methods: Mean, Standard deviation, Minimum, Maximum, t-test
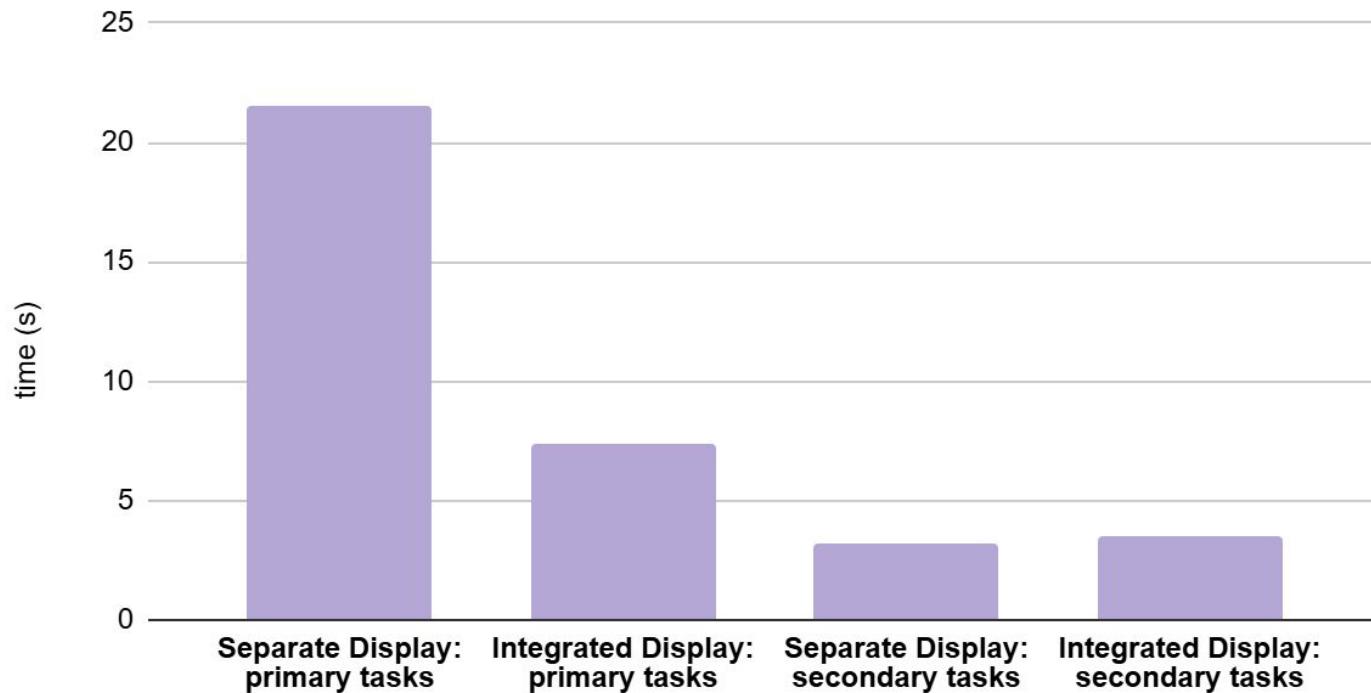
- Limitations of methods: sensitive to outliers, small sample size

Data Organization:
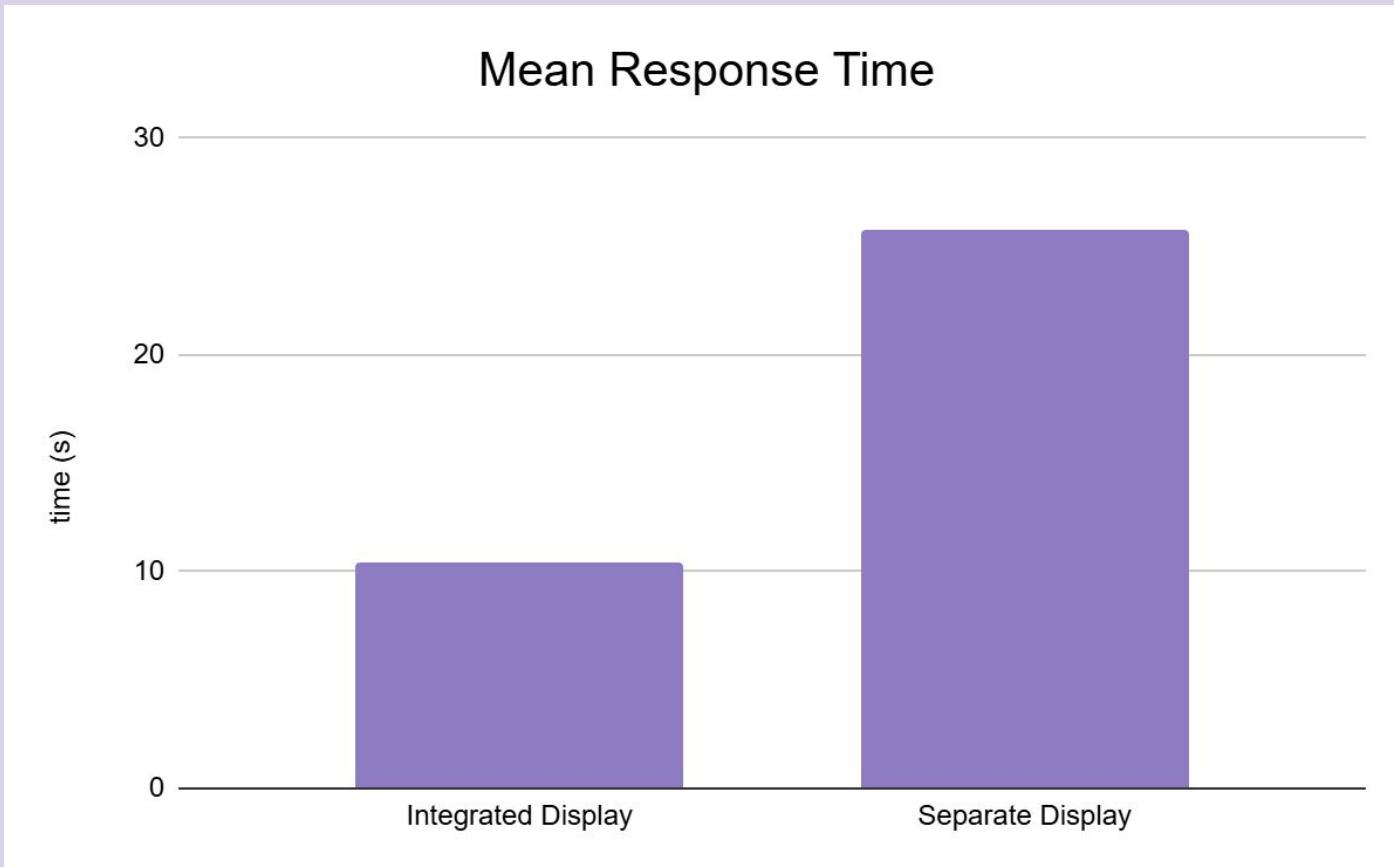
1. **Task Type Analysis:** Compared response time for "Primary" and "Secondary" tasks.
2. **Person Performance:** compared the response times for each person under different tasks.
3. **Display Performance:** compared response times for each task between integrated and separate displays. Averaged the response time of the two participants.

Task Type Analysis
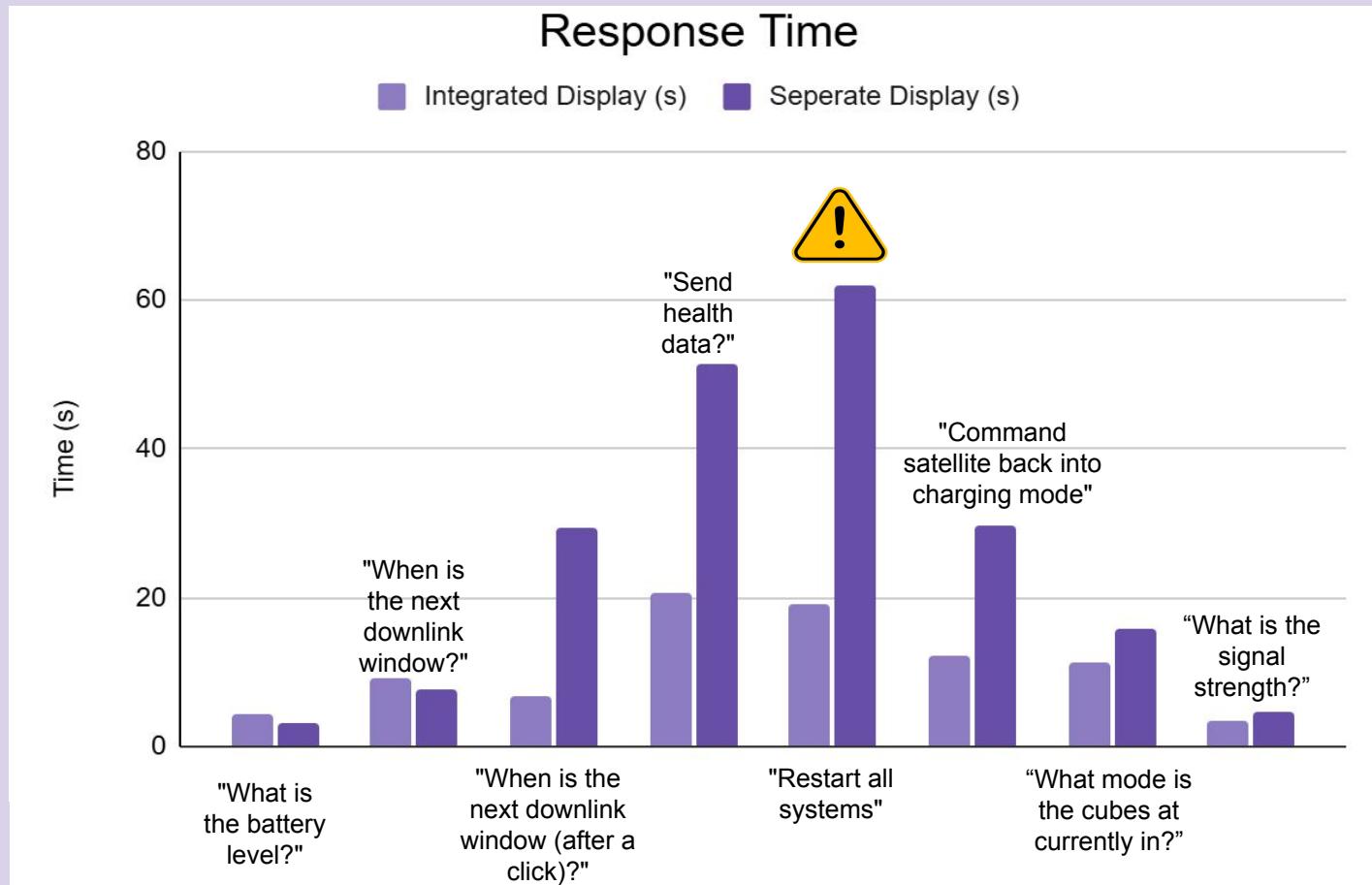
Separate vs Integrated mean response times for primary and secondary tasks

Display Performance

Display Performance - Task Breakdown

Conclusions

- Integrated display was preferred over separate flight and system displays
- Touch screen input was preferred over keyboard and mouse
- Drop down commands were preferred over pseudocode

Recommendations

- Downlinking windows should be more clearly shown on the display
- There should be clear visual or auditory alerts when a value on the screen changes
- More emphasis on status of returned data should be included

Next Steps

- Edit the display according to conclusions and recommendations
- Consult with the CubeSat team to determine needs for collected data visualization
- Scale the display and testing to more closely resemble its usage

References [IEEE]

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[2] "KiboCUBE Academy Introduction to CubeSat Attitude Control System." Available: https://www.unoosa.org/documents/pdf/psa/access2space4all/KiboCUBE/AcademySeason2/On-demand_Pre-recorded_Lectures/KiboCUBE_Academy_2021_OPL14.pdf

[3] "Mission Control Screens Depicting Various Views Stock Footage Video (100% Royalty-free) 3284882 | Shutterstock," Shutterstock, 2016. https://www.shutterstock.com/video/clip-3284882-mission-control-screen (accessed Oct. 28, 2024).

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[5] "Satellite Control Systems | Space," Terma, 2024. https://www.terma.com/products/space/tgss-based-operations/ (accessed Oct. 28, 2024).

[6] Trevor C. Sorensen et al., "A University-developed Comprehensive Open-architecture Space Mission Operations System (COSMOS) to Operate Multiple Space Vehicles," *SpaceOps 2012 Conference,* AIAA 2012-1296468. June 2012.

[7] M. Massimino, "MECE 4811 Aerospace Human Factors Engineering: Lecture 5." Available: Canvas.

[8] M. Massimino, "MECE 4811 Aerospace Human Factors Engineering: Lecture 6." Available: Canvas.