The International Space Station (ISS) began payload operations in earnest in 2000 with the arrival of the Expedition 1. To date, ISS has offered Principal Investigators (PIs) a reliable platform for microgravity research, having hosted thousands of onboard science experiments. Most of this research is supported by experiment hardware and software and many include a crew-operated Graphical User Interface (GUI).

The purpose of this article is to share information with PIs and Payload Developer (PD) teams about the processes, standards, and guidelines applicable to crew GUI design that must be complied with when planning payload software. The goal is not to enumerate *all* of the ISS display standards, but rather to highlight design guidelines and the ISS Program milestones for verification and approval of onboard crew displays.

Displays flown aboard the ISS are subject to review and compliance with usability goals derived from ISO 9241 and the display design standards outlined in SSP 57000, Appendix T. The standards are maintained by the Integrated Display and Graphics Standards (IDAGS) Panel in a joint agreement between NASA and its ISS International Partners (IPs). As you develop your display products the Payload Displays Review Team (PDRT), your IP Point of Contact (POC), or IDAGS representative (hereafter referred to as display reviewer) are ready to assist you with interpretation and application of those requirements. Developers who determine the need for an onboard crew GUI to support their investigation should expect to deliver their Initial Displays with the Critical Design Review (CDR) technical data package submittal. The CDR milestone occurs during the Design & Analyze phase of the Payload Integration Flow.

Display Platforms - Laptop. ISS laptop computers fall under one of two categories: Portable Computer System (PCS) and Station Support Computers (SSC). Commercial off-the-shelf products (currently the HP ZBook, Windows 10 OS) are modified to operate in the ISS IVA environment and are located in the NASA US Lab, COL (Columbus), and JEM (Japanese) experiment modules. PCSs are the primary interface to the ISS command and control systems. Regarding Payloads, PCS may be used to monitor payload health and status information and payload ancillary data, as well as receive caution and warning messages and view/execute automated procedures. Unlike SSC-based GUIs, PCS crew interfaces are designed to SSP 50313, Display and Graphics Commonality Standard (DGCS). SSCs are the basic platform for laptop-assisted payloads and offer the crew the ability to conduct payload operations.

Crew displays support payloads are typically stand-alone experiments or rack-integrated investigations operated in facilities located throughout the station. Two major facilities, the EXPRESS (EXpedite the PRocessing of Experiments to Space Station) racks and the Microgravity Science Glovebox (MSG) both have laptop integrated software.

Display Platform Types - Non-Laptop. Today, payload experiments are supported by diverse crew display interfaces. Display technology has evolved beyond the standard laptop format. Small- and medium-sized integrated displays – built on LCD, LED/OLEDs and even e-Paper platforms, appear on hardware front panels and on commercial handheld devices throughout the ISS research modules. Mobile digital devices including tablets (e.g. Apple iPad and Microsoft Surface Pro), as well as Smartphones (e.g. iPhone; Android) have been used to host stand-alone payloads, as well as software-based crew experiments, surveys, and inventories. Wearables, including “smart suits” for dynamically capturing crew physiological signals, as well as commercial- or modified headsets for AV/VR-based studies are seeing more common use aboard the ISS.

Commercial Software Products. Stand-alone payloads, or experiments accompanied by commercial handheld devices with an integrated display, have been frequently used. Commercial- or Modified Off-the-Shelf (COTS/MOTS) software requires careful selection. The developer will be asked to supply vendor user manual information and representative screenshots of the nominal display operational sequence. Depending on the extent of the alterations to the original application, and similar to custom-designed software, MOTS products will be evaluated against Appendix T. The display reviewer will take into account the developer’s ability to implement changes in order to bring final product into compliance with the SSP 57000 display specifications. If firmware is used in order to modify the software to the display platform, these changes are not reviewed and should be transparent in the final GUI design.

Pre-Design Analysis. Usable payload crew displays are the product of a well-conceived payload operations concept and thorough functional/task analysis. Functions allocated to the payload software are decomposed and the essential requirements for a display interface may emerge. Moreover, your analysis may point to a need for direct crew control or monitoring of the onboard payload experiment. This systems approach is recommended as a reliable method for arriving at a GUI that incorporates only those functions and features that are *necessary* and *sufficient* to service the payload.

Iterative Review and Design Support. Payload display development is an iterative process. The functional/performance requirements for the design --its detail and complexity, your familiarity with design for the microgravity environment, as well as other variables will determine the length of the development process and the effort required to arrive at a final usable product. It is incumbent upon the developer to deliver initial displays early in the payload development cycle. This is to enable the iterative design process to happen, as well as get in front of other software integration verification activities, including pre-launch baseline data collection (BDC). Your initial displays may be simple mockups of some or all of the proposed GUI functions, design elements, a spatial layout, and the primary/secondary windows comprising the navigation scheme. The display reviewer provides the opportunity to engage in small team or one-on-one work sessions to gather information about the ops concept and the crew role in servicing the payload. They are mindful of the PD product design capabilities, including any limitations or constraints; i.e. budget, schedule, in-house expertise, design-build tools.

Display Verification. Approval of payload crew displays is a multi-step process. The successful application of this process relies on timely submittal of display operations products and cooperative/productive technical discussions between you, the PI/PD customer, and your display reviewer. Initial crew displays (or concepts) are delivered, reviewed, and updated. Displays are assessed for compliance with the SSP 57000 standards and evaluated for usability. The flight candidate crew displays may require, at the judgment of the display reviewer, a formal usability evaluation (i.e. test) to assure on-orbit acceptability for crew use.

Design issues revealed during usability testing (if any) are resolved per the developer's feasibility to do so. Open items are documented as deviations and accompany the final displays during baseline.

It should be noted, Facility investigations are subject to integration requirements unique to the host platforms. EXPRESS laptop rack integrated software will undergo Payload Software Integration Verification (PSIV) testing to ensure safety and compatibility. Subrack experiments operated in the Microgravity Science Glovebox (MSG) have their software hosted on the MSG Laptop Computer (MLC).

Display Approval. The final flight candidate crew displays are submitted as a set of static screenshots in the appropriate change reviews for final board approval. Confirmation of board approvals is transmitted to the PD team for closing their display requirements. As the PD, your GUI verification tasks are essentially completed. Your final display file should indicate the flight software version and, if applicable, the build number. Any further updates to the GUI at this point will need to be submitted for another review.

Post-Flight / Reflight. Payload operations completed on ISS, and then planned for later re-flight will restart the display review process. Updates to the software version will be submitted to the display reviewer and processed as an update to the original baseline.

Display Design/Essential Guidelines. Your GUI will likely not use all of the design elements in Appendix T. Nor are all standards applicable to all platforms. However, there are basic guidelines all developers should follow. For example, when considering the physical dimensions for a hardware front panel display, developers should carefully assess the depth/breadth/frequency of the visual information to be presented versus the screen size they have selected and ask: "Do I have enough display?". Variables such as data type, operational complexity, simultaneous viewing requirements, crew viewing distance, etc. should lead you to select a hardware platform that offers adequate active screen space, refresh capability, illumination (i.e. performance characteristics). Displays should be readable and legible at the required viewing distance, while avoiding too-dense content or excessive need to scroll/navigate between screens.

Effective design helps achieve the goals of maximizing mission success, enabling efficient use of crewmember time, minimizing training time, and facilitating error-free operations. The well-designed GUI will minimize input errors and alert the crewmember when they do occur. The design should prevent actions that can harm the payload and should safeguard critical commands from accidental activation; e.g. through two-step confirmation. The display should facilitate error recovery. For example, if a payload runs on battery power, the display should indicate the battery health status within one action, as well as show when the battery is low and requires a recharge. The display element(s) for initiating the command should be visually distinct from other display controls; e.g. for navigation.

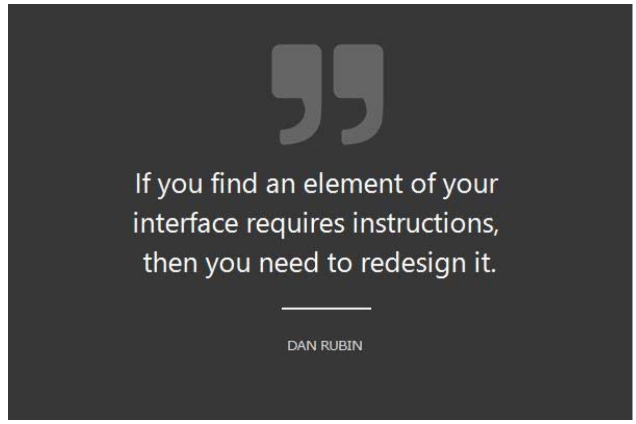
Health/status monitoring displays should try to incorporate a left-to-right, top-to-bottom spatial layout. Depending on your design approach, title bars should be included to aid crew navigation. The navigation path should comprise the minimum possible number of steps for translating between/within the main display and secondary screens.

Human interface design for the microgravity environment presents unique challenges and visual displays are no exception. Depending on the type of interface, for example when using a mobile device, changing orientations within an application cannot rely on an automated function and will require a manual user action. Cursor control is more difficult in weightlessness. Display control elements need to be adequately sized and spaced to enable easier actuation. GUI design for crew use requires forethought and understanding of working in space and the impacts on visual acuity. NASA surveys of over 300 astronauts who had flown orbital missions of over six months concluded that half experienced changes in both near- and far-sightedness. Problems were also reported by astronauts whose missions lasted less than six months. Older crewmembers (aged 40+) were shown to be more predisposed to vision problems after as few as six weeks in weightlessness.

Feedback. ISS payloads must follow strict specifications for how cautions, warnings, and alerts are annunciated, including color, tone, text, display symbols. Message Dialog Boxes provide feedback. They are used to ask questions, confirm actions, and warn of problems (e.g. input errors). Flash coding (blinking) can be effective, although this feature should be used sparingly and add meaning to the crew's awareness of the payload status and/or critical actions to be taken. Haptic feedback, unless intended as the core feature of the investigation (e.g. a wearable device), likewise should be used sparingly. Haptic cues should be distinguishable and carry meaning while not interrupting other critical inputs, such as a voice channel. Auditory feedback with a display can be useful when the user may be at a distance from the visual display. Auditory feedback should not be the sole indicator due in part to the ISS IVA high ambient noise environment.

Help. Your display may require provisions for context sensitive help. Help content may include explanations of hot keys, acronyms and abbreviations, error messages, or explicit tutorial guidance helpful to the user when performing complex tasks. Tool Tips are an embedded form of display help. If used, tool tips should be brief and minimally intrusive. They are useful in providing additional detail about a specific GUI element, for example a required data input. The software should enable tool tips to be disabled.

Other Commonly-Used Design Elements. Appendix T provides the developer with good guidance for most all of the commonly-used elements comprising a payload GUI, including menus, data fields, buttons, checkboxes, sliders, tabs, graphical symbols/icons, meters and graphs, clocks/timers, logs, status indicators, labels, terms and text, and colors. Some design guidelines to keep in mind: The ISS is an international laboratory with crewmembers having various native languages. To avoid confusion in date format, time is shown as DD MMM YY, e.g. 12 NOV 22. When inserting graphs in your GUI, identify all parameters (e.g. include a legend) and axes. Status indicators are graphically analogous to LED indicators on hardware. Both should follow sound design principles regarding color appropriateness, coding (e.g. blink coding) and logic. Labels and text on displays should be brief and descriptive. A note on terms: The use of acronyms and abbreviations on displays should be limited. The terms/text/labels on your GUI will undergo a nomenclature review per SSP 50254. Command button labels should begin with an action verb, be limited, and address the action being performed. Paired terms for payloads are defined in the standards, including those to avoid. For example, instead of “Enable/Disable”, say “Enable/Inhibit”; and rather than “Abort” use “Stop”, “Halt” or “Terminate”, as appropriate. When assigning graphical symbols to display elements, start with those listed in Appendix T, then select from symbols native to the operating system (or industry) standard. If these are insufficient, you may elect to create a custom symbol. The IDAGS team maintains an electronic symbols library for developers. Finally, colors applied to payload GUIs are not for aesthetics. Rather, there are a limited number of colors for payloads and each has a specific, defined meaning. Developers should not use yellow and red, as these are reserved for ISS System caution and warning. The color orange is used to indicate payload alerts or to draw the crew’s attention to an error or out-of-limits condition.



Conclusion. Albert Einstein said, “If I had an hour to solve a problem and my life depended on the solution, I would spend the first 55 minutes determining the proper question to ask, for once I know the proper question, I could solve the problem in less than five minutes.” Good GUI design flows from developers taking the time to plan and determine what the crew needs to see and do in order to produce great science.