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ABSTRACT

The International Space Station (ISS) will be the largest structure ever built in space. Differences between ISS and previous NASA vehicles led to developing new labeling methods, conventions and material. The challenge was to provide clear and meaningful identification, location, operations and safety information for the crews who will assemble, maintain and live onboard ISS.

INTRODUCTION

NASA had extensive experience with labeling manned spacecraft from Mercury capsules through the Space Shuttle Program. The Mercury Capsule was small and had a short-duration mission, measured in minutes. Apollo and Skylab vehicles were larger and their missions were longer, measured in days and months. The Space Shuttle is an aircraft-like transportation system within the atmosphere and a small space station while on short-term orbit. The Shuttle flight deck provides labels similar to an aircraft flight deck, while the remainder of the vehicle can be labeled for mission-specific payloads carried in the internal decks and the external payload bay. The many providers of payloads contributed a variety of labels for internal vehicular (IVA) and extravhicular (EVA) activities that the Shuttle crews performed to complete their missions. Spacelab and Spacehab are vehicles that travel to orbit as part of Shuttle missions. All these programs contributed to NASA's labeling experience for manned vehicles. Finally another dimension was added by the Hubble Space Telescope Program. Hubble is not a manned vehicle, but it required astronaut crews to perform EVA to launch it and to provide maintenance, hardware upgrades and repairs. It has long orbital times in the space environment between upgrade and repair missions, so the external labels provided information about durability of materials and long-term value of information.

The long-term mission of ISS added new challenges of extended exposure to the rigorous space environment and the need for label information to be consistent during assembly of the constantly-growing, ever-changing vehicle and during on-orbit life in which the emphasis will be operations and maintenance. One particular challenge was the large size of ISS which prompted an emphasis on location information to avoid lost time and disorientation during movement around the inside and outside of the large structure.

GENERAL BACKGROUND

Of all the difficult design activity that goes into a large and complex project like the International Space Station, what could be simpler than labeling the hardware to ensure everyone knows what it is, what it does and what to do with it? Labeling may be less complex than many other design solutions such as thermal control, structural integrity, and power distribution that keep ISS functioning; but designing labels was not as simple as it may have first appeared. This paper will discuss challenges that faced NASA and its contractors in providing information for the on-orbit crew interface. Most of the explanation will be about the labels for the specific pressurized modules and truss segments designed at Boeing, Huntington Beach, California. Other Boeing locations and other contractors may have had different hardware and contractual reasons for designing labels. An emphasis in this paper will be on permanent labels that must last the life of ISS.

A great deal of human factors research has been done to develop and standardize words and symbols that highly skilled operators must use to interact with their equipment. Designs for labeling aircraft, military systems, air traffic control centers, nuclear power plants, automobiles and other operator environments benefited from that research NASA operates its complex systems with highly educated and highly skilled astronauts from the USA and our international partners, who trained extensively to do their tasks in space. Although NASA 's label design requirements relied to some extent on the body of knowledge created by scientific research, they relied even more extensively on operator experience and feed back to shape those requirements. Particular for the EVA environment, there is very little research that doesn't rely heavily on the experience of a relatively small group of individuals.

SPACE STATION BACKGROUND

NASA experience in all aspects of spacecraft design for human interface was incorporated in the Manned Systems Integration Standards (MSIS). During the Space Station Freedom Program MSIS-STD-3000, Vol. IV provided general guidelines for labeling the crew interface along with other aspects of human factors and ergonomic design. The International Space Station Program, which NASA and the international partners began as a follow-on to Space Station Freedom in 1994. The new program included several documents for ISS crew interface that were derived from the MSIS series:

- Space Station Program (SSP) 50005, International Space Station Flight Crew Integration Standard (NASA-STD-3000/T)
- SSP 50006, International Space Station Internal and External Decals and Placards Specifications
- SSP 50007, Space Station Inventory Management System Label Specification
- SSP 50014, International Space Station Utility Coding Specification

These documents contained requirements and guidelines for several types of labels. In addition SSP 30575, Space Station Interior and Exterior Location Coding System provided the basis for location information for Space Station Freedom and was modified for ISS.

There were some difficulties in reconciling the specific contract language that referenced these documents and determined responsibility to design labels for each of the major USA hardware providers (now all part of the Boeing Company). Those contract difficulties led to two major contract changes to clarify label design responsibilities and specific design requirements. One change was specific to internal labeling and the other was for external labels. Both changes eliminated SSP 50006 as a requirements document and placed nearly all label design requirements in SSP 50005 with supporting information in some additional reference documents. It is not the purpose of this paper to dwell on the contract concerns except to say that those changes were implemented in 1997 and 1998, much later than the original contract. The main effect was that labels were added to existing hardware rather than incorporated into the design from the beginning. Some of the design challenges were exacerbated by that late implementation.

TYPES OF LABELS

The label design requirements can be grouped into four general label types, based on the information they convey to the crew. These types of requirements apply to both IVA and EVA, so they can be covered together.

<u>Location Coding Labels</u>

NASA provided the ISS Program a location coding document (SSP 30575) that defined a system identifying codes for all the locations in the ISS down to orbital replaceable units (ORUs). Those codes incorporated up to nine alpha-numeric characters. The characters represented elements (Nod1, PMA1, S0), directions (S = starboard, P = port, D = deck) and relative position on an element (Bay 1,Bay 2, Bay 3).

This location coding system will be important to both internal and external operations. There will be many circumstances in which ground monitoring will provide status information for the crew in orbit. The crew will also communicate questions or problems back to ground. An important link for the communicators on the ground and in-orbit is this reference system that helps them in discussing where the focus of status or concern should be. Location codes will help to pinpoint the subject of their discussion. Location codes will help simplify such discussions, e.g., "Go to ORU X at location NOD1D3"for IVA and "Go to WIF, NOD1, BAY01, 01 for EVA. The unique positioning of elements of ISS required special coding. Specific label requirements describe what items require the location coding references to actually be applied as a label to the item or to a specific area.

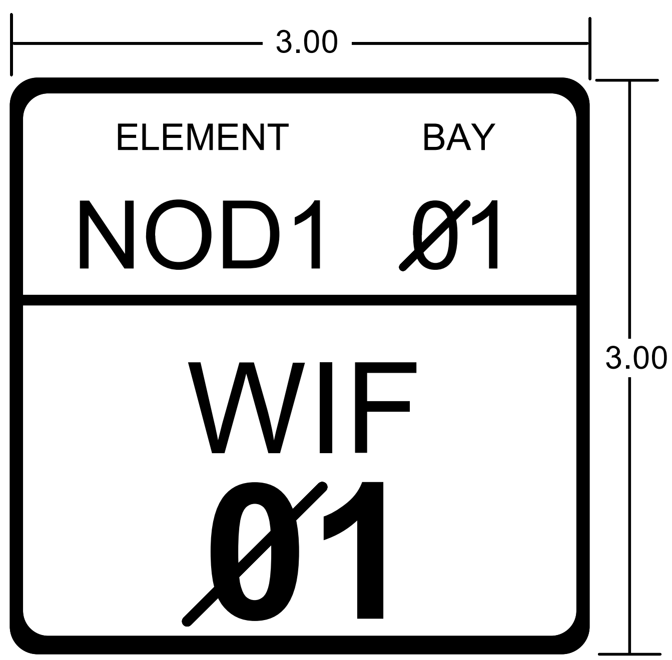

Figure 1. Location Coding Label – This is an example of a location coding label that identifies the element, bay and number of a worksite interface (WIF) that is used by EVA crews to mount their portable foot

restraint. The information on the label will be in the EVA checklist that describes the EVA activity being performed. Dimensions are in inches.

Identification Labels

SSP 50005 defined what items must be identified by labels and an additional document (SSP 50254, Operations Nomenclature) specified the nomenclature and abbreviations that were acceptable for identification labels. Reference designations carried over from Space Station Freedom or names of new items provided by the contractors made up much of that nomenclature. In most cases, NASA used nomenclature that had specific meaning to crew operations and crew experience. The specific components that could fail or require maintenance and replacement during ISS life were identified as Orbital Replacement Units (ORUs). Components that appeared visibly similar required identification labels to distinguish them. Identification labels were placed in a prominent location where the crew could view it, avoiding the need to check manufacturers' nameplates to distinguish among similar-looking hardware. A NASA plan to identify each ORU with a four-digit code in addition to its nomenclature was not developed in time for publication of label requirements. To meet that future plan, the ORU labels designed by Boeing Huntington Beach, incorporated four correctly-sized zeros as placeholders for that code. NASA could then add the correct coding identification prior to launch. In addition to ORU labels, all electrical and fluid lines and their connections required identification labels and those types of labels made up the largest quantity of labels needed for the early ISS modules and the interior truss segments.

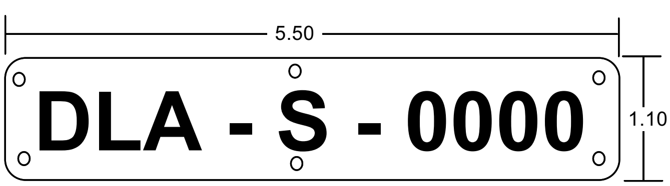

Figure 2. This is an example of an ORU identification label for the Drive Lock Assembly, starboard, on the Solar Alpha Rotary Joint (SARJ). Note that the four zeros were provided as a placeholder for NASA's more specific identification code. The nomenclature is from SSP 50254. Dimensions are in inches.

Safety Labels

This type includes caution, warning and emergency use labels. They have very specific requirements for wording, font size, color and distinctive border markings. NASA provided many of these labels in standard formats in a catalog (JSC 27260, Decal Process Document and Catalog). In some cases, unique size and surface characteristics led Boeing Huntington Beach to design specific safety labels for those needs.

Crews working IVA in the internal, shirt-sleeve environment, must be warned of risks to themselves from hazards, such as electrical shock from powered circuits. They must also be directed to emergency use equipment such as fire extinguishers, breathing apparatus and escape routes. In addition, IVA crew must be made aware of damage they could do to sensitive equipment by improper handling, such as the need to eliminate electrostatic discharge (ESD) by using ground straps. Caution, warning and emergency use labels were designed or chosen from NASA's catalog to meet those IVA needs.

The external environment of the station is inherently hazardous. All electrical and fluid connections are a risk if opened when powered or pressurized. The EVA Maneuvering Unit (EMU), the protective suit worn by the EVA crew, protects the crew from most electrical and fluid hazards due to its insulating material. In addition, the crew member in the EMU does not effect hardware sensitive to ESD. The crew must be warned of credible hazards that could damage the protective capabilities of the EMU or could directly disable the crew. Labels were needed to help the crew control the risks from hazards such as pinch-points, stored energy, stay-out zones for load-sensitive hardware, rotating equipment and radiating antennas. A decision was made not to put warning labels at all electrical connectors and pressurized fluid-line, quick-disconnects. That decision was based on the belief that too many safety labels for those obvious hazards, would dilute the importance of other labels that were needed for less obvious risks. The EVA crew will be protected by checklist steps that require electrical circuits to be disabled prior to disconnecting, and protective isolation valves or venting methods to be used prior to disconnecting pressurized fluid lines. An example of the design of a warning label for rotating equipment is shown in Figure 3. Because no emergency-use equipment was used on Boeing Huntington Beach external hardware, labels for emergency use were not required.

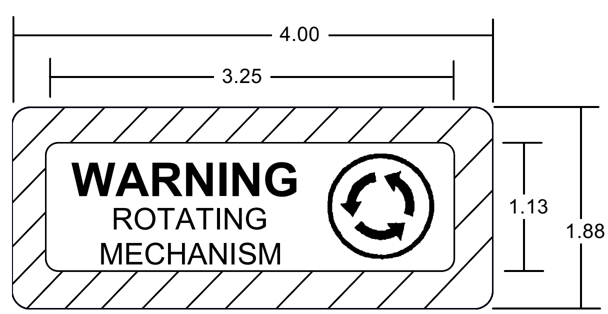

Figure 3. EVA Safety Label – This is an example of a safety label copied from SSP 42205 Space Station Program EVA Safety Label

Specification. Some of the specification details have been edited to simplify the figure. The actual label border is an alternating gold anodize and black striping. The words and symbols are black on silver white matte aluminum. Dimensions are in inches.

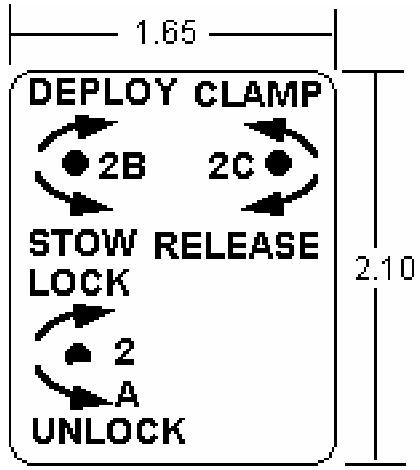

Figure 5. Operational Label – This is a complex mapping label that provides instructions to aid the EVA crew in carrying out checklist activities on the SARJ DLA. The label is to be located as close as possible to the equipment interfaces being operated. Dimensions are in inches.

<u>Operations Labels</u>

The design of this type of label depends on the operation of the specific hardware. All crew operations are carried out in accordance with descriptive checklists. The ISS Program approach was to limit wording on instructional labels and let the checklists direct the crews' actions. The purpose of this approach was to avoid clutter of information, so that only the minimum needed was provided on labels. It was a philosophy similar to safety labels. Operations labels varied in their content from simple alignment marks, arrows and other aids used to direct focus while following checklists, to direction-of-turn for drive mechanisms and simple instructions for latching and locking mechanisms. Those were the most common uses for operations labels on the Boeing Huntington Beach hardware.

Figure 4. Operational Label - This is a simple instruction label that is sewed onto a Beta Cloth or multilayer insulation blanket or shroud using the holes at each corner. It instructs the crew where to open the blanket or shroud as part of a procedure that is described in more detail in an EVA checklist. Dimensions are in inches.

CHALLENGES TO MEETING LABEL REQUIREMENTS

<u>Internal Labels</u>

One concern in designing ISS internal labels, was the length of the mission. Permanent information had to be correct for all the changes that could occur during assembly and final ISS configuration or crews will not consider labels to be credible. If a labeling system loses its credibility for even low-value information, it may also lose it for high-value information. These kinds of challenges led to some flexibility for installing internal labels. ISS will have many configurations during its lengthy assembly, so that location coding labels reflecting obsolete configurations would not be helpful to a crew member using supplementary lighting during a power outage, for example. In fact, safety could be jeopardized if in an emergency, crew members had no faith in escape route labeling because labels were outdated and could not be trusted. . The Node 1 ports will have different modules attached at different times. One solution to obsolescence of routing information was to provide clear pockets for EXIT location labels so they could be changed out at different stages of ISS buildup.

The short duration of Shuttle missions put the crew at less risk for out gassing and other material concerns, although designers must always take such risks into consideration. Designers for internal ISS labels had to work closely with material experts to ensure that internal labels would not contribute to a toxic environment for the long-duration missions. Another challenge for internal labels designers for Boeing Huntington Beach was that the three pressurized mating adapters (PMAs) will be exposed to external space environments during some parts of the mission. External label materials were used for those interiors to avoid damage from the orbital environment.

Internal labels materials were not limited in the color spectra (as long as they met toxic requirements), so any colors needed as cues were available for the internal volumes. However color was used very little for internal label design. Instead, consistency of design was considered to be important, so reliance on clear–cut, consistent, and commonly-used nomenclature was applied as a more important design factor for internal labels than color cues. Emergency- use equipment were labeled with the correct red color borders to identify their special status.

Placement of internal labels in locations that supported viewing was sometimes a challenge. The internal surfaces were often irregular; fasteners and other attachment methods often interfered with placing labels. The late definition of labeling requirements led to some components being provided by subcontractors without labels. That contract challenge became a design challenge. The plan was that labels would be added later to meet the new requirements. In some cases, an area was identified for placing labels, but even that was difficult because size and information requirements were not known when the hardware was designed. If the final requirement stated certain font sizes and nomenclature that could not be fitted into a small space on the hardware then an optimum viewing placement was not easy to achieve. Some labels had to be moved prior to launch when last-minute crew reviews showed they would be difficult to see. Early experience on Flights 2A and 2A.1 have led to suggested changes to the placement and content of labels in the US Laboratory.

<u>External Labels</u>

Label materials for external use were one of the early challenges facing label designers for the long-duration mission of ISS. The flight crew integration standard required labels to meet the same functional life requirements as the equipment they were mounted on or associated with. That ensured that inks, pigments and other organic materials could not be used for external labels because of environmental life limits caused by Atomic Oxygen, a corrosive element existing in ISS orbits. This environmental effect limited available colors, adhesives and protective materials and shielding. An example of a material that was limited in use by the environment is clear Teflon, originally thought to be a promising material for protecting pigmented labels. Clear Teflon becomes opaque when exposed to the orbital environment. Although it would protect the label, it also would prevent viewing of it. This doesn't investigate the technical and scientific details of these material problems, but will note their limiting effects on label material choices and ultimately on the visual cues that external labels could provide. As noted in the discussion of internal labels, color is an important part of visual communication, particularly in safety-related information. Yellow and red are commonly used for cautions and warnings. Material designers determined that a gold anodize could be produced for EVA handrails that were normally yellow on other space craft. This same gold anodized material could be used as a substitute for yellow on warning labels. A red material was found to meet environmental life requirements for labels although it did not match the MSIS spectral requirements for red safety labeling. Because the costs of producing a useable red were high, the program accepted a reduced dependence on red as a cue in certain types of external labels such as those that point to the Airlock. Those Airlock labels became part of the location coding requirements

The most useful material that was found to meet the long-life requirements for external labeling in harsh environments was a photosensitive aluminum foil (Metalphoto or its equivalent) that provided black (photographically exposed) characters, symbols and borders on a silver white (unexposed aluminum) background. The foils specified by Boeing Huntington Beach were available in hardened aluminum (H18) with matte finish in the following thickness (5, 8, 20 and 32 mil) and an annealed, dead soft aluminum with satin finish in a 5-mil thickness. Most labels attached to hard surfaces were the 5 mil thickness, while labels tied to cables and soft surfaces such as insulation were 20 mil thickness. The thicker material was used on soft material because the thicker edge could be rounded to eliminate sharp edge hazards, that were not a risk when the 5 mil labels were securely attached with adhesive to hard surfaces.

Another concern and challenge for external label designers was how to attach the information to the equipment. Riveting of labels to already existing hardware was not a preferred method, because it was costly to add holes when the labels were not a part of the original design requirements. Anodizing to a surface is a long-lasting method, but it can be quite difficult and expensive with large surfaces that must be masked and submerged in the processing tank. These concerns led to a general approach of adhering metal foil labels to surfaces using adhesives. Launch vibration, thermal cycles and crew activity were all enemies of that approach, but an adhesive material (3M Y-966 or its equivalent) was determined to have excellent results in all those environmental situations. The history of Y-966 on short-term Shuttle flights and material testing in the laboratory coupled with its ease of application made it a good choice. Soft surfaces such as Beta Cloth (fiber glass) and multilayer insulation (MLI) required foil labels to be stitched to the surface. Thicker foil with rounded edges was used to avoid safety issues and meet requirements to avoid sharp edges. Careful stitching was done to ensure the insulating properties were not defeated by the labels' "shorting" the dead spaces between layers of insulating blankets. Material processes were developed and incorporated into Boeing Huntington Beach drawings to ensure proper mounting. Similar challenges for mounting labels to electrical cables and fluid lines were met by tying labels with surgical-knot precision near connectors and quick-disconnects and at required intervals on cables and lines for identification. Labels could not be attached directly to connectors and disconnects because of thermal limitations and other specific material properties.

Thermal effects were one of the major challenges for designing external labels. The size of labels had to be kept to a minimum to avoid degrading thermal-performance of the equipment being labeled. Locating labels on surfaces was restricted by the type of surface material and other surface features such as fasteners and strengthening reinforcements. As previously stated, soft thermal covers required stitching or tying of labels to the insulating material, but the size of those labels had to be kept to a minimum. Also labels had to be carefully located to avoid degrading the performance of the insulation because of reduced its area and interference with its optical properties.

Another restriction of labels size was electrical grounding requirements. The requirements for long life of labels that led to using metal labels and their insulating adhesive and stitching materials also led to concern for grounding of the metal labels if they were larger than a threshold area. Grounding was necessary to avoid the buildup of surface charge that comes from crew movement across the metal surfaces that are electrically isolated from the main structure. For metal surfaces greater than 100 cm^2 (15.5 in^2), the potential for the build up of hazardous electrical charge existed. The undesirable expense and weight of adding grounding through any method presented a challenge to keep label sizes below that threshold. In some cases the label sizes for telerobotics viewing required that grounding provisions such as screws or rivets had to be added, because those labels could not be minimized below the threshold area and still be visible for the telerobotic video.

Another concern for designing external labels was that the EVA crew moved over the surface where the labels were placed, threatening damage to the thin, foil labels. The primary answer for that challenge is the previously-described reliable adhesives and stitching materials as well as simple design solutions such as rounded corners and rounded edges to avoid assault by the gloves, boots and tools of the EVA Astronaut . Where curved surfaces required labels, dead-soft aluminum labels were used that were formed to match the radius of the curve. High quality workmanship in applying these various label was an important factor in ensuring that the labels remain attached to the hardware they were designed for. Standard methods and procedures were modified as needed to improve and adjust workmanship to meet all those needs.

Most challenges to designing external labels were met by reducing label size to the minimum and carefully mounting them where they had the least environmental impact on their associated hardware. Still the information content had to be readable and meaningful for the crew activity. In cases where the requirements for information content conflicted with environmental limitations on label size a requirements exception process was used to resolve the problem. On the whole, label design met the label requirements with few exceptions ..

HOW IT ALL CAME TOGETHER

NASA provided the labels to its contractors through the Johnson Space Center Decal Design & Production Facility. This facility provided a limited catalog of standard labels and information about available label materials and adhesives. Labels can be ordered by contractors as government furnished material (GFM) but must be accompanied by released contractor drawings if the label is not included in the catalog. Boeing, Huntington Beach designed nearly 10,000 different labels to meet its label requirements. Those label designs were documented in label specifications that assigned part numbers called out in design and installation drawings. Internal and external label specifications for identification, location coding, safety and operations provided label designs that meet the ISS label requirements and deal with the challenges of the ISS environment.

CONCLUSION

International Space Station requirements for labels led to some interesting challenges in meeting those requirements when much of hardware design was already mature because of development during The Freedom Program. Lessons learned from each assembly and expedition flight will lead to further changes to label requirements for future space programs.

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REFERENCES

1. SSP 50005, International Space Station Flight Crew Integration Standard (NASA-STD-3000/T), DCN-001, Nov 17, 1998, as modified by Space Station Change Notice 549, March, 28, 1998.
2. SSP 42203, Space Station Program EVA Location Label Specification, SCN-09, January 12, 2000.
3. SSP 42201, Space Station Program EVA Equipment Identification Label Specification, Rev B, SCN-05, March 7, 2000.
4. SSP 42205, Space Station Program EVA Safety Label Specification, SCN-04, June 19, 1998.
5. SSP 42207, Space Station Program EVA Operations Label Specification, SCN-08, November 2, 1999.