Dynamic Display of Electronic Crew Procedures for Space Station

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Crew procedures for the Space Shuttle are carried on the Orbiter in loose-leaf books. For the Space Station, NASA intends to store similar procedures primarily in electronic media, to be viewed and executed from onboard display work stations. The formats of today's space operations procedures have evolved to suit the characteristics of the paper medium. The author claims that displaying electronic images of procedures laid out on paper would guarantee an awkward interface for the user, and would ignore the inherent power of the computer-driven display. An alternative "dynamic" user interface is proposed in which procedure displays are formatted automatically in real time, and are optimized "on-the-fly" according to the connectivity of the procedure steps and the changing needs of the user. This approach will also benefit procedure authors, who will no longer need to create layouts. Other features include 1) responsive browsing and search capabilities, 2) procedure logic and tracking aids, and 3) provision for static, dynamic, and interactive displays of procedure support information. It is claimed that this dynamic interface will make procedure execution faster, more accurate, and more acceptable to Space Station crew members than displays replicating paper images.

Paper Procedures for Space Shuttle

WHILE the Shuttle Orbiter is on the pad awaiting launch, a NASA official enters it and places critical paper documents in dedicated stowage areas. Collectively called the Flight Data File (FDF) for historic reasons, these loose-leaf books weigh about 95 lb for most flights and have exceeded 150 lb for the longer Spacelab flights. The FDF comprises a minimum of 25 titles, with some books duplicated in different onboard locations. Copies are also provided in Mission Control Center.

The preponderance of information in the FDF books is operations procedures. These procedures govern the management of the vehicle and onboard systems, and the pursuit of all mission objectives. Standards for writing procedures and for management and control of the entire Flight Data File are well documented.[1] FDF modifications are approved by the Crew Procedures Control Board, a governing body that includes an astronaut representative.

The NASA Johnson Space Center (JSC) organization responsible for managing and producing the FDF books also will be responsible for control of its Space Station equivalent. They have sponsored MITRE in the development of Space Station FDF requirements,[2] and are sponsors of the present work.

Electronic Procedures for Space Station

The Space Station analog to the FDF, including all crew procedures, is intended by NASA generally to be stored in, and used from, electronic media instead of paper. This change is consistent with both the thrust of changing technology and the mandate from the U.S. Congress for emphasis on automation and robotics in the Space Station program.[3]

Crew procedures are operations procedures whose execution is managed by a human user, whether or not computer assisted. Excluded are procedures embedded in onboard core systems and procedures to be generated by software in real time, e.g., for control of core systems. With some exceptions (including emergency safety-critical operations), NASA intends for crew procedures to be executed from display screens at fixed and portable work stations onboard the Station.

The multidisciplinary Space Station Operations Task Force has suggested that "one specific goal for reducing the cost of operations is the effective use of scarce resources on the manned base. Crew time will be one of the most expensive and scarce resources...."[4] Computer assistance in executing individual procedure steps is already planned;[2,5] examples include retrieving data from sensors and transmitting commands to onboard systems. The broader issue of a user interface specifically adapted to facilitate the use of electronic procedures should be explored with a view toward improving crew efficiency.

Importance of the User Interface

User interfaces (that is, human-computer interfaces) are often regarded as mere front-end attachments to a system. The interface proposed here relates to procedure functionality in a pervasive way, and cannot be so regarded. In designing it, the author has proceeded in accord with Donald Norman's view: "The needs of the user should dominate the design of the interface, and the needs of the interface should dominate the design of the rest of the system."[6] To better judge the needs of the procedure user in Shuttle and Station environments, MITRE interviewed approximately 30 NASA JSC workers, including astronauts, flight directors and controllers, procedure writers, and FDF managers. Involvement of the users in the design of a new user interface is critically important. This practice helps to ensure that the design is truly practical and that the benefits will justify the cost. The procedure display concepts proposed here will undergo review by NASA and it is hoped that people with a variety of skills (such as those interviewed) will participate broadly in the assessment. The usability of displayed procedures as judged by the current and future astronaut crew will be an important determinant of success of the electronic approach, in general, for the Space Station.

The dynamic interface proposed here will require human factors studies and usability experiments. Studies of fixed format procedure displays have been performed at the JSC Human-Computer Interaction Laboratory.[7]

Giving Up Paper

Conversion to electronic media can overcome these disadvantages of paper in onboard operations:

1) Paper has substantial weight and volume.

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2) Its information is in a predefined organization, and is static.

3) Its information can only be in one place at a time.

4) Paper does not stay current (i.e., updates don't destroy obsolete copies).

5) The handling of physical objects is somewhat difficult in zero g.

The use of electronic media also will extend to the ground-based process for authoring, modifying, and validating Space Station procedures.[8] End-to-end electronic processing has many benefits, including an ability to transmit updated versions simultaneously to storage media at all necessary onboard and ground locations.

But abandoning paper is not without penalty. The interviewed JSC personnel expressed concern over several perceived disadvantages of "going electronic." In addition to questions of portability and annotatability (which are being addressed, but lie outside the scope of this paper), their concerns focused on the user interface. A major worry was possible slowness and awkwardness in having to manipulate displayed images by scrolling and paging commands, compared to the familiar handling of paper sheets in books.

An assumption implicit in their comments is that the display screens would be showing replicas of paper procedures. This idea is certainly a natural one, but one that somehow makes it difficult for us to see alternatives to it—a "paper mind-set," so to speak. This author began the current work with the same limiting perspective.

Replicating Paper Images

Putting paper images on the screen is only one approach to user interface design. It may be the most obvious choice, but for some kinds of information it is also the worst. It retains characteristics appropriate to the attributes of paper and fails to exploit those of the new medium. Geoffrey James[9] has observed that

> a page displayed on a screen has all of the disadvantages and none of the advantages of a paper page.The screen page is locked into a formal-dependent structure, rather than a content-dependent structure.... In a hard-copy book, the reader can easily flip from one part of the book to another, or mark pages that might come in handy. The reader can also skim hard-copy pages without reading, remembering that a certain item was in a certain portion of the book. None of this is practical or convenient with a page display.[9]

Space Station procedures probably will be more often executed than "browsed," but the paper image approach still relegates the computer to the role of a page-turning device, one to which it is not really well-suited. With displayed page images, users would indeed have to give scrolling and paging commands of some kind while executing or browsing through procedures. If today's Shuttle procedure formats were retained, a user sometimes would have to locate an offscreen step knowing only the step number, or visually follow a connecting line that extends off the edge of the display.

There is also a question of display "framing"; what will be the size relationship between the information shown on the screen, and the information on the page whose image is displayed? Ideally the display and the paper page would be identical. With today's small personal computer screens, this often requires putting less information on the paper page—only a "screenful." If this equivalency can't be achieved (e.g., onboard display screen size could vary), it is better for a display to show more than a page than to show a partial page. Even if the layout of each paper page were somehow optimized, a display of only a portion of the page might make poor use of display screen space. It would provide awkward functionality as well: with partial page images, the user would have need for both local-page scrolling and page-change scrolling. For example, a user executing a procedure might scroll the current page, arriving finally at a reference to an off-page step. He or she would have to give commands to locate and display the target page, then give repositioning commands if the target step is not in view. These problems and others must be addressed when designing an interface oriented to paper pages.

The Role of Spatial Layout in Procedures

Spatial Encoding of Information

The term "real estate" will be used in the sense that advertising people use it: as a reminder of the fundamental worth of any potentially information-bearing space, in any medium. Viewed as an information storage medium, paper can be said to offer real estate for the storing of static information in user-selected locations. Spatial relationships between information elements can be used to encode additional information implicitly (e.g., the left-to-right sequence convention in our written language). Retrieval of the implicit information requires that the retriever/decoder know the rules used by the storer/encoder.

Figure 1 shows an unusual procedure format in which sequence information has been separated from the executable steps. Figure 2 has the same elements rearranged, such that the top-to-bottom order of sequence rules no longer corresponds to the left-to-right order of steps. Hence, the last vestige of positional meaning has been removed from the diagram. Although Fig. 2 is hard to understand, it completely defines the same procedure as Fig. 1. Both steps and step-sequence information are essential in a procedure, but Fig. 2 demonstrates that positional meaning is not essential to convey the sequence.

Surely no one would recommend separating sequence information from procedure steps. The point is that since the

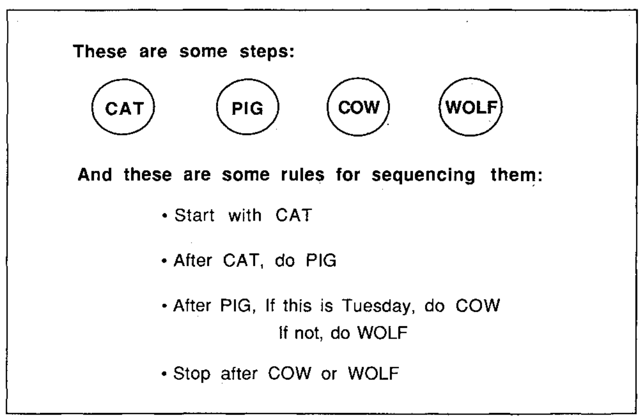

Fig. 1 Sample procedure showing separate elements.

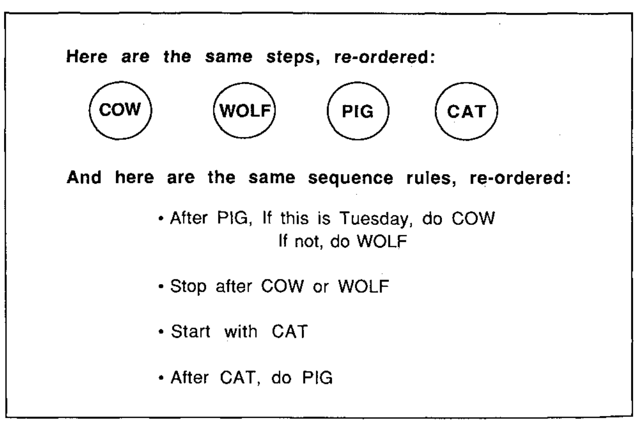

Fig. 2 Sample procedure with elements reordered.

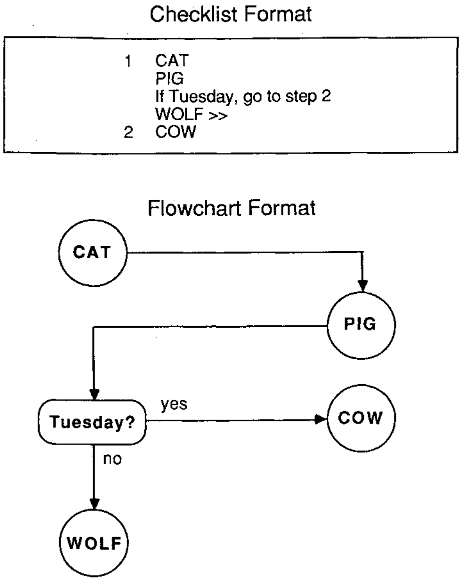

Fig. 3 Sample procedure in Shuttle formats.

MN BUS UNDERVOLTS/
FC VOLTS-AMPS

SHORT or DEGRADED FC
If no MN BUS tied to affected FC MN BUS:
If affected FC/MS BUS connected to P/L BUS:
1. Go to step 14
If affected FC/MN BUS not connected to P/L BUS:
2. Perform step 3 of affected FC SHUTDN, 5-8 (Cue Card), then:
If FC VOLTS < 32.5 (FC SHORT):
3. Affected FC REAC VLV - CL
If first FC failure:
4. Perform BUS TIE, 5-8 (Cue Card)
5. If all MN BUSES tied, MNC TIE BUS - OFF
6. Go to PWRDN, LOSS of 1 FC/1 FREON LOOP, 10-18 >>
If second FC failure:
7. Perform affected MN BUS LOSS ACTION, 5-15, then:
8. Go to PWRDN, LOSS of 2ND FC 10-20 >>
If FC VOLTS > 32.5 (BUS Short):
9. Go to affected MN BUS LOSS ACTION, 5-15 >>
If bus tied to affected FC/MN BUS:
10. Untie buses
If short eliminated and MN BUS unpowered due to bus untie:
11. Go to affected MN BUS LOSS ACTION, 5-15 >>
If short not eliminated and MN BUS unpowered due to bus untie:
12. P/L PRI (three) - OFF
13. Perform BUS TIE, 5-8 (Cue Card) - good FC/MN BUS to unpowered bus, then:
If affected FC/MN BUS connected to P/L BUS:
14. Disconnect P/L BUS from affected FC/MN BUS
If short eliminated:
15. Go to P/L BUS LOSS ACTION >>
If short not eliminated:
16. Go to step 2
If affected FC/MN BUS not connected to P/L BUS:
17. Go to step 2

Fig. 4 Portion of Space Shuttle procedure, checklist format.

spatial encoding of information is optional, one begins "from scratch" in deciding how to use it. Each display medium will present alternatives for encoding information spatially, but both the alternatives and their value to a given application will depend on the nature of the medium. (This is why, for example, electronic wristwatches are suited to showing time in digital form, while mechanical ones encode that information in angular position.) As display media, paper and computer screens have very different attributes and, as will be seen, the layout conventions that serve us well for procedures on paper will not necessarily serve us well on the screen.

Use of Layout in Shuttle Procedures

The spatial layout of today's Shuttle procedures will be examined briefly. Two common formats are the checklist and flowchart formats. Figure 3 shows the preceding sample procedure as it might appear in these formats. Figures 4 and 5 are portions of checklist and flowchart procedures used in Shuttle operations.

Shuttle checklists are frequently used in off-nominal situations to put equipment in a safe configuration quickly. They are also used in most maintenance procedures and some payload procedures. Steps in checklists are arranged vertically, and sequencing is defaulted top-to-bottom. This avoids using real estate to specify most sequencing, but makes branching a cognitive process for the user. Step number references and vertical lines (descending from branching steps) guide the user in finding remote steps. The checklist format is best when there is no branching or a small amount of binary branching. Because it is compact, it gives the user a broad visible scope of context.

The flowchart format is used extensively in diagnostic and corrective procedures. It is fully two-dimensional, since a step may be in any compass direction from another step. The text of a step can be folded into multiple lines. Groups of steps are boxed and connected by sequence arrows in typical flowchart fashion. Interspersed among the executable steps are diagnostic statements in boxes of unique appearance (see steps 35 and 37 in Fig. 5) Step number connectors are employed to reference remote targets. Since multiple exit lines can be drawn from a branching step, complex branching is easily accommodated.

The default sequencing in the checklist and the arrows in the flowchart are examples of ways to define step sequence with a minimal effect on the user's thought process.

Putting Procedures on Display

Improving On Fixed Images

The display of fixed images is entirely appropriate for most of the nonprocedural, reference information in the Station FDF. A fixed geometry is in fact intrinsic to such things as diagrams, tables, and photographs.

To improve on the displayed page image approach for procedures, assistance with screen navigation could be provided. In Shuttle flowchart procedures, both interpage and intrapage connectors are used. (The latter are needed when it is awkward to draw a line to the target; note the flow from step 35 to step 39 in Fig. 5.) One could retain the connectors and offer automatic jumping (e.g., via hypertext). One could even have the author construct the entire procedure as a unit. This would eliminate page boundaries entirely, and eliminate or minimize the use of connectors. One also might have the computer modify the image in real time. It could shift procedure steps to fit better on the screen, eliminating unreadable, partial steps at the perimeter by either pulling them fully into view or pushing them out entirely. The "rubber-sheet geometry" would improve the content and appearance of any portion of a procedure on display while preserving the topology of its author-created layout.

But these are only variations on the fixed-geometry theme. If one pushes beyond the paper mind-set, and considers abandoning the idea of a fixed paper image entirely, new possibilities will emerge.

Potential of the New Medium

Electronic data storage capacities probably will continue to increase as projected by workers in those technologies. (They have the best track record at predicting.) If so, truly massive amounts of information should be storable onboard the Space Station with minimal weight, volume, and power requirements. Since limits in the costs of creating and managing a large reservoir of information would be encountered before storage became a problem, the amount of "electronic paper" available onboard can be considered effectively unlimited. On

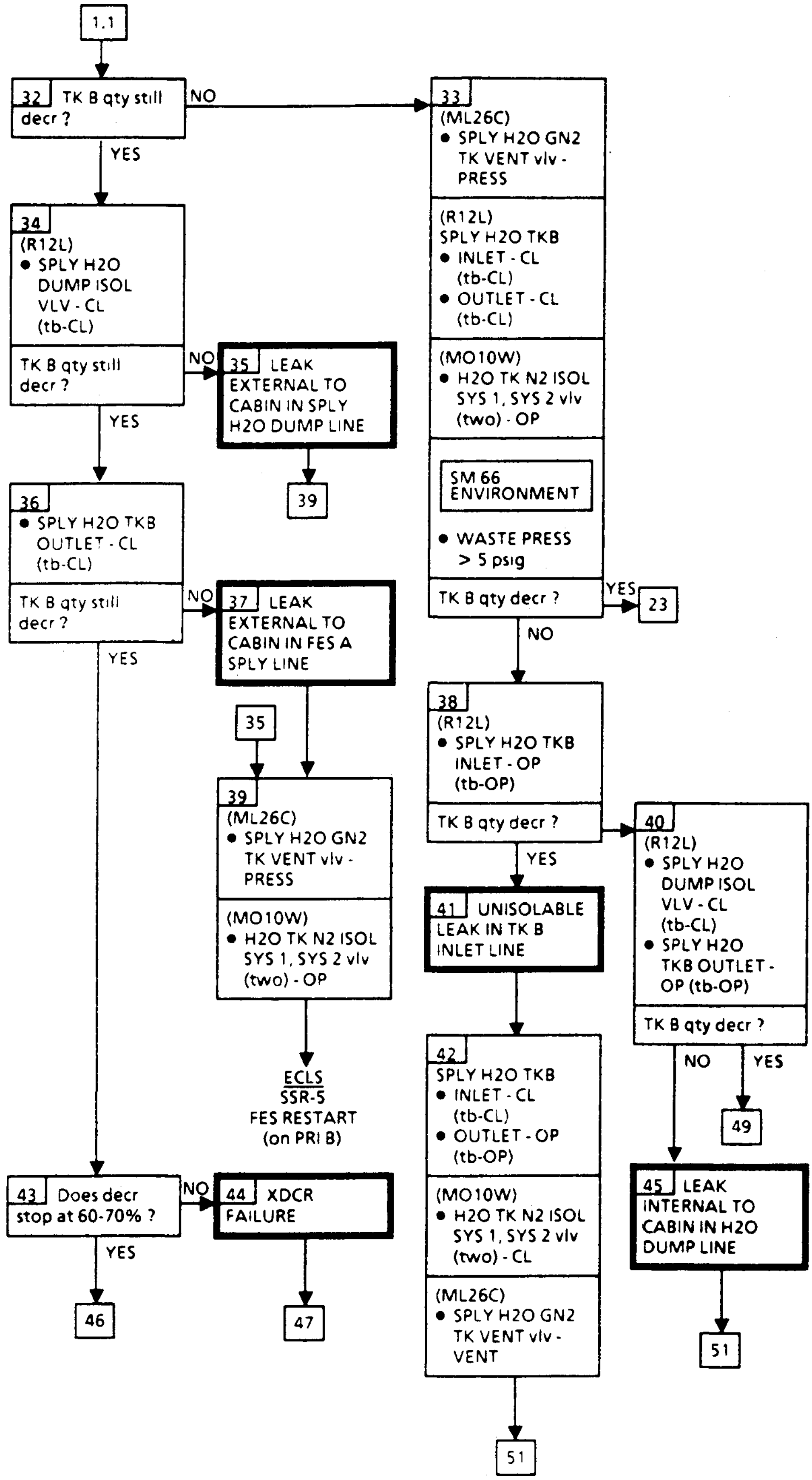

Fig. 5 Portion of Space Shuttle procedure, flowchart format.

the Space Station, it is not information storage that will replace paper as a limiting resource, but display screen area.

Display screen area is the new real estate of the computer age. Planning for its judicious use must be a fundamental requirement in the design of the Space Station user interface at all levels. For this reason, the author opposes approaches that would reserve a fixed region of the screen for some infrequent occurrence such as display of a warning message. The visual and audible output capabilities of the medium are ample to guarantee attracting the user's attention to an emergency message. If an application that manages its own display is running, the message could be passed to it for superimposition on the screen at a low-penalty location.

It was said earlier that displaying paper images would not exploit the attributes of the new medium. What are these attributes? In contrast to paper, the display screen has several remarkably superior characteristics:

1) The information it shows can change with time (thus allowing information to be encoded temporally as well as spatially).

2) It can display specific combinations of information never conceived in a human mind.

3) It can create those combinations on-the-fly.

4) It can do all of this responsively, following the wishes and whims of the person using it. A screen need not be used merely for passive information display; it can be used actively for information interchange. The computer-driven display medium is not only potent enough to provide functionality for the lost advantages of paper, but through a dynamic interface, it can provide a level of smart assistance that will make procedure execution faster, more accurate, and more acceptable to astronauts and ground crew than any frozen paper-image technique.

Dynamic Display of Crew Procedures

MITRE's goals for this user interface design were 1) to use the display screen area more efficiently than paper images would use it, and 2) to provide better functionality for the user through a combination of dynamic and static display methods.

Central Concept

The central concept is that real time software will extract information from an operations data base and construct a display that shows precisely the procedure steps and support information the user needs to see at each phase of execution. The display will be reformatted dynamically as execution advances, or as the user browses within the procedure.

This idea, amplified by the details to follow, defines a high level user interface concept for crew procedures. Work on a standard Space Station-wide user interface is underway,[10-13] but complete descriptions and requirements are not yet available. Some of the features to be identified in subsequent sections may use capabilities of the final standard interface, while others may conflict with it and require modification. Still others will be fully application-specific, i.e., built into the procedure display software.

The ability to slave display work stations together (so that two or more onboard and/or ground workers can view and use the same procedure display) is assumed. This feature is included in FDF requirements.[2]

None of the capabilities described below requires artificial intelligence (AI) methods or other sophisticated techniques. Algorithms and heuristics within today's state-of-the-art will serve.

Automatic Formatting

The formatting rules will be designed to arrange procedure steps and supporting information to display a maximum of information consistent with clarity. Steps that are candidates to appear in the display will be selected from the data base according to their *execution sequence in relation to the current step.* (The current step is tracked by the computer and is always visually identifiable.[2,5]) The steps will be placed so their relationship to the current setup will be shown clearly. The text of a step can be folded into a shape convenient to the needs of the moment. Candidate steps that don't fit on the screen will be removed from consideration. If the current step is a branching step, all potential next steps will be present and shown in correct relation to it, space permitting. Display composition rules will include specification of some desired balance between steps prior to, and steps following, the current step. Since formatting goals cannot all be satisfied in every case, the display management logic will consult predetermined priority information to resolve tradeoffs.

The software authoring tools provided to procedure writers[8] will include these dynamic display capabilities. The authors will have to specify steps and step sequencing, but automatic formatting will eliminate their need to create layouts.

Automatic Sequencing

The burden of following sequence logic will be shifted from the user to the computer. After a branching step, the next subsequent step will be determined by computer resolution of the conditional(s). The information required will be obtained from user inputs and/or by automatic means, according to the nature of the branching step The use of step connectors and step numbers for display screen navigation will be eliminated. (Step identifiers have other uses, though, and must be retained.)

Violation of the author's intended sequence will be permitted, but will be accompanied by a warning message. Some sequence violations have known potential for danger, e.g., risk of explosion of a fuel cell. These violations could be outlawed entirely, or might require approval by specified onboard and/or ground authorities. Procedures also must be capable of being aborted.

Separation of Steps and Support Information (Supps)

Many crew procedures need support information, such as tables, drawings, and photographs. In the dynamic display concept, such information will be shown separately from procedure steps, in windows. Steps will be composed solely of text, while support information may contain any combination of text and graphical information, and even video or audio.

Each body of support information to be displayed discretely is called a "Supp." Some Supps will be passive; others will be interactive. Supp windows can present predefined (static) information or real-time (dynamic) information, such as numeric values, animated schematics, or closed-circuit TV. Information outside the operations data base will be displayable in a Supp, provided software for its display can be accessed and invoked. Procedure-related Supps might include: conditions for procedure execution; information to clarify steps or assist in decisions; interactive Supps (see the next section); notes, cautions, and warnings (as used in Shuttle procedures); schematics, diagrams, photographs; procedure rationale (design knowledge).

Supps can be mandated by the procedure author, or requested at any time by the user. The author can specify that a Supp be logically attached to a single step, to a range (or ranges) of steps, or to the entire procedure. The Supp window will appear on the screen when its designated first step appears, and will disappear when its designated last step leaves the screen. Hence, Supp displays will use real estate only when the user needs to see them. Similarly, when the user is browsing, any author-mandated Supps will appear and vanish appropriately with movement through the procedure. User-requested Supps will always remain onscreen until canceled.

Interactive Supps

Plans for the Space Station include the elimination of many of the panel-mounted display and control devices used on the Orbiter, and replacement of them with displayable "soft" equivalents. A soft switch, for example, might consist of an icon resembling a switch and having a different appearance for each state, possibly with displayed words such as "ON" and "OFF." The user interface must provide a simple means for the user to "flip" the switch, which then would cause the same real-world effect as a physical switch. Sounds can be used to augment the visible changes. A particular advantage of soft controls with respect to electronic procedures is a reduced need to be somewhere other than the work station when performing operations.

When procedures call for the crew member to operate soft controls, they will appear within interactive Supp windows. Such Supps also will be the vehicle for the entry of information such as experiment results, yes/no decisions, discrete commands, etc., during procedure execution. Interactive Supps will be defined by the procedure author. Regardless of purpose, these support displays will need commonality in appearance and function, and should conform to the Stationwide user interface standard.

Establishing a Modular Geometry

Limiting the display to a modular, rectangular geometry will simplify the formatting logic while keeping an acceptable information density. A rectangle (box) will enclose each sequential group of steps intended for nonbranching execution; that is, only the final step can branch. A means must exist for the user to accurately discriminate between steps inside the box; it must ensure that multiline steps are not easily mistaken for multiple steps. (This is provided for in Shuttle flow charts; see Fig. 5.) Where branching occurs, appropriate step boxes will be visibly connected, perhaps by arrows.

Supp windows will be positioned with at least one edge coincident with an edge of the display screen. The formatting software should be able to use windowing services of the standard Station user interface in generating Supps. Step boxes and Supp boxes normally will be tilted, i.e., nonoverlapping.

Opportunistic Use of Screen Real Estate

The procedure display software will adjust for the size and resolution of the display screen being viewed by the user. Screen size could vary between fixed and portable work stations onboard the Station, and perhaps between multiple displays of a single work station, if these exist. If work stations having larger screens were to be installed during an upgrade, the automatic formatting software would take immediate advantage of them with no reprogramming necessary. This could occur during program development as well as during Station operations.

When a new Supp is to appear onscreen, existing text information will be shifted, if necessary, to provide space. Step text may be reshaped during such an adjustment. These onscreen changes might be thought visually disturbing, but note that whenever the user is executing a step, or whenever he or she stops movement during browsing, the display will be motionless.

Because of Supps, the area available for steps can be nonrectangular. The step formatting logic, therefore, should be capable of working within any contiguous area having a perimeter composed of vertical and horizontal line segments.

Establishing a Default Sequence

Few procedure steps are branching ones, so a default rule will substantially minimize use of real estate. A top-to-bottom default is chosen for crew procedures. It is intuitive and matches the Shuttle checklist standard. The alternative of a left-to-right default would more frequently force step text into multiple short lines, reducing reading speed and possibly impairing accuracy.

The top-to-bottom default will apply within step boxes (i.e., the enclosed steps are intended for top-to-bottom execution) and between step boxes (i.e., the next box is below the current box). This means that "future" is always downard from the current step, and "past" is always upward from that step. Displayed information, therefore, will slide upward across the screen as execution proceeds. Below a branching step, the formatting logic will lay out the alternative target boxes in a horizontal row, when space permits.

Navigating and Browsing

A simple means must be provided for requesting single step advancement during execution; a spoken command or a single keystroke would do. (Interface designers often give the user redundant methods for doing routine things.) The direction of browsing also must be easily controllable, perhaps by use of a zero-*g* mouse (one constrained not to float away). Bringing the mouse icon closer to the edge of the display could be made to increase the scrolling speed.

The procedure user must be able to browse any time, whether executing or not. If execution is underway, the current step will be suspended (or carried to completion, if automatic) when browsing begins. Since the display software is designed to connect steps only via sequence logic, one browses either downward toward the future or upward toward the past. Left and right "jogs" will select alternative paths at branching steps, since target steps are usually positioned laterally. (Because more than one execution path can *enter* a single procedure step, browsing upward could also offer left/right choices.)

True leftward or rightward scrolling is not meaningful here, since there is no two-dimensional image being scrolled. Hence, pointing to the extreme left or right could be used for other purposes such as zooming out to the "browser map" or expanding a macro step (both explained in subsequent sections).

The set of steps already executed is called the trail. When browsing in the past direction, trail steps will be visibly distinguishable from others. Also, when browsing toward either past or future, it is possible to encounter steps that have not been executed, and can never be encountered during the current execution. These steps are inaccessible because they exist on a branch of the logic tree that has already been bypassed. The current step, the trail steps, the inaccessible steps, and the steps that are potentially executable, must all be distinguishable from one another via some visual technique.

A means must be provided for returning immediately to a suspended current step. If browsing and not executing, the user will be able to identify any step as an "anchor" step (analogous to putting your finger on a page while you browse a book). An immediate jump back to the anchor step must be possible. An anchor step is treated like a suspended current step when browsing, i.e., the user will be able to see which steps are potentially executable after the anchor and which are not. Anchor steps will be particularly useful in writing and editing procedures.

Other browsing features will be 1) a capability for jumping to the top of the procedure (or to the point of entry), 2) an ability to advance or retreat to the next branching step, bypassing intervening nonbranching steps, and 3) a way to jump immediately to a step based on its identification code.

Browser Map

At any time, the user will be able to zoom out to a tree-like diagram showing the topology of the whole procedure. This full-screen "browser map" will identify a "you-are-here" point, and will allow the user to zoom back to the detailed procedure at that point, or to any other point selected from the map.

The map is prepared by the procedure author. It would display a few words for each major section of the procedure, and would show the most important decision points and the paths that emanate from them. The display software will impose no minimum requirements on the browser map; a short nonbranching procedure might have no map, whereas a long, detailed procedure might present a map rich in structure. Experience will help determine an appropriate balance between cost and utility. The browser map is another feature valuable in procedure development, as well as in Station operations.

Macro Steps

In Shuttle operations, many short procedures are called by other procedures, like subroutines in a computer program. The called procedures sometimes are sufficiently well known to astronauts to allow their execution from memory. The advisibility of NASA's permitting this with Space Station procedures is controversial. If it is permitted, a "macro" feature could display the procedure name in one step position, in lieu of the component steps. This macro step would be visibly marked as such. When encountering it, the user would have a choice: 1) expand the macro, and view and execute its component steps, or 2) perform all requisite actions from memory, then advance past the macro as if it were a normal step. Novices with respect to the macro procedure (including astronauts in training) would execute it in expanded form. If NASA policy required it, macro expansion could be enforced (or inhibited) in prescribed operations scenarios, for specific macros, and/or for specific users.

There are two alternatives for presentation of the expanded macro. In the simpler "reference-only" approach, the component steps would appear in a Supp window. In that form they could not be tracked by the computer when executed, nor could any step make use of automatic execution features. This alternative uses the normal Supp capability and requires little or no additional software.

In the "in-line" approach, the expanded steps would immediately replace the macro step in connected sequence. The component steps would then be treated as if they were part of the procedure originally; tracking and all other features would be available. This in-line alternative has the advantage of helping prevent the inadvertent omission of a step by the user.

"Fisheye" Compression

A wide-angle or "fisheye" camera lens provides a broader view at the expense of distortion, mostly at the periphery. The fisheye concept has been applied to logical as well as spatial entities.[14] With a displayed procedure, one can provide fully detailed procedure steps in the center of the screen, but show summary information instead of steps at the top and at the bottom. Several narrative summary lines can describe the functions of several blocks of procedure steps that would not themselves fit on the display.

The summary at the top of the screen, for example, might remind the user that outlet valve B was opened and that water tank B was dumped to 80%. Or in a malfunction procedure, a diagnostic summary could be provided in this fashion (but in standard nomenclature): "fuel cell 2 has a short or is degraded; payload bus was disconnected; condition was unchanged." Summary information at the bottom of the screen will give the user a sense of what is to follow.

This "fisheye compression" feature will give the user a broader past/future view of the procedure, with some loss of detail. The formatting software will automatically expand bottom summary lines into detailed steps as they move upward during execution, and will collapse the steps into summary lines as they approach the top of screen. The procedure author can create summary information as deemed appropriate; the formatting software would adapt to any amount of summary, or none. Entries written for the browser map might do double duty as summary items. Names of macro steps would certainly be used in both summary lines and maps.

Combining Procedures

There are occasions for combining or connecting procedures. In Shuttle operations, for example, an astronaut might need to move from a nominal procedure to an off-nominal procedure (e.g., from a system safety checklist to an appropriate malfunction procedure for troubleshooting). In general, two or more Space Station procedures may be related 1) by serial execution, 2) in subroutine-like nesting, or 3) in ad hoc nesting, in which the user suspends one procedure, performs another, then returns to complete the first. These cases, and intermixtures of them, must be supported by the interface. In the first two cases, it would be *possible* to display the first step of the new procedure directly after the last step of the old, but such a seamless appearance is not acceptable. Astronauts and ground crew are sophisticated users who must remain fully aware of context, so transfers between procedures must always be explicit on the screen. Procedure names also must be shown, regardless of how the user might be nested into the procedural activity.

Use of Hypertext

In its simplest form, hypertext is electronic documentation prepared such that activation of a "source" point on a given display will cause appearance of "target" information in place of the current display. The target information may be remote in the current document, or from another document. In dynamic display, such hypertext "links" could be predefined by procedure authors to allow users to make meaningful "jumps" within and between procedures. Conventional hypertext capability may be among the generic services provided to all Space Station applications, but since it can be expected to be oriented toward linking information objects that are predefined in a static layout, it is not clear whether the generic service would be useful in supporting the previously described dynamic display features.

However, hypertext will be able to provide linkage between procedures and other kinds of information, e.g., schedules that call out procedures. It also can facilitate retrieval of relevant information desired by a procedure user. Before executing a maintenance procedure, the user might examine a list showing the needed tools and supplies (this is planned for on-orbit Station maintenance). The user might then proceed to a display of the onboard inventory, and finally to a resupply schedule. Hypertext linkage information connecting procedures and/or other elements in the Station FDF will need to be managed along with the information itself. Appropriate software tools will support creation, editing, and testing of the linkages. The tools must provide assistance in updating hypertext links affected by revision of their source or target information elements.

Display Screen Appearance

No drawing is offered here to show the reader how the display screen might look in the proposed interface. There are two reasons. First, only high-level concepts have been described, and drawing a picture would require presenting low-level details. Second, and more important, the essence of the proposal is dynamic display, so a realistic sense of the capability cannot be conveyed through a static medium. Development of a functioning prototype has been recommended; this is being considered by NASA.

An ability to discriminate between the current step, trail steps, etc., has been mentioned. The methods preferably would not use real estate, but in any case must not interfere with the clarity of displayed information. The use of pale colors in background (not in the text) would seem ideally suited to this. Implicit techniques such as using background colors have the advantage that their meanings are reinforced by experience.

Although the Man-Systems Integration Standard[10] specifies color displays for Space Station, the issue remains in dispute. Also, it has been proposed that color be used only to emphasize information already on display (called redundant recoding); this would be very limiting for many applications. (Human-computer interface guidelines advise that, "color should be redundant with other stimulus features in case of failures in the color display hardware that put the monitor in a monochrome mode and because a relatively large percentage of ... users may have deficits in color vision."[12]) While color would enhance their usability greatly, all features of the dynamic procedure interface could be implemented in black and white.

A list of candidate ideas for visually encoding or enhancing procedure information follows; some have been mentioned previously. The list is offered merely to illustrate the flexibility of the display medium for detailed interface design.

1) Color of text.
2) Variable fonts (size, style, boldness, underlining).
3) Color and texture of background.

4) Variable gray tones, color saturation, or hue.
5) Inverse video.
6) Blinking (used sparingly with small information items).
7) Meaning attached to direction on screen (left-right, up-down).
8) Simulated third dimension.
9) Motion, local or full-screen.
10) Changing appearance of mouse icon.
11) Shape of step enclosure.
12) Color of enclosure.
13) Line width for enclosure.
14) Connecting lines, if used (width, color, arrowheads, dottedness).

Work stations on the Space Station will doubtless provide several devices/paths for information flow, and the procedures interface might employ capabilities in addition to visual aids. For instance, output sounds, words, or phrases could be helpful in alerting the user, reinforcing information on display, or in confirming actions taken by the user or computer.

Remarks

Computer displays are often perceived as cumbersome in the handling of information originating in paper documents. The current work shows that, when the user interface is designed specifically for the new electronic environment, a display screen can be surprisingly robust in communicating such information to users. The author believes that the practice of abandoning page images in favor of dynamic presentations will become increasingly frequent in applications where support of the user is of particular importance.

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