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Human Factors Assessments of the STS-57 SpaceHab-1 Mission

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ACRONYMS

ASPEC	Application Specific Preprogrammed Experiment Culture
A/G	Air to Ground communications
CGBA	Commercial Generic Bioprocessing Apparatus
CMAM	Commercial Middeck Augmentation Module
dBA	Decibels with the A-weighted network applied
DSO	Detailed Supplementary Objective
ECLSS	Environmental Control and Life Support System
EFE	ECLSS Flight Experiment
EMU	Extravehicular Mobility Unit
EPROC	Electronic Procedures Experiment
EVA	Extravehicular Activity
FCSD	Flight Crew Support Division
FD	Flight Deck
FDF	Flight Data File
HFEL	Human Factors and Ergonomics Laboratory
HFA	Human Factors Assessment
HFA-EPROC	Human Factors Assessment Electronic Procedures Experiment
HFA-LIGHT	Human Factors Assessment Light Experiment
HFA-SOUND	Human Factors Assessment Sound Experiment
HFA-QUEST	Human Factors Assessment Questionnaire Experiment
HFA-TRANS	Human Factors Assessment Translation Experiment
ICOM	Internal Communication
IVA	Intravehicular Activity
JSC	Johnson Space Center
MIL-STD	Military Standard
NASA	National Aeronautics and Space Administration
NASA-STD	National Aeronautics and Space Administration Standard
NSTS	National Space Transportation System
NC	Noise Criterion Curve
QUEST	Questionnaire
OMS	Orbiter Maneuvering System
OVEI	Orbiter Vehicle End Item Specification
PSE	Penn State Experiment
PTS	Permanent Threshold Shift
SAREX	Shuttle Amateur Radio Experiment-II
SH	Commercial Middeck Augmentation Module
SLS	Spacelab Life Sciences
SpaceHab	Commercial Middeck Augmentation Module
STS	Space Transportation System

TAGS	Text and Graphics System
TDS	Tools and Diagnostics Systems
TTS	Temporary Threshold Shift
USML	United States Microgravity Laboratory
WCS	Waste Control System

SUMMARY

The human factors assessment (HFA) experiment was composed of five separate studies. These studies investigated crewmember translation through the tunnel joining the middeck and SpaceHab, noise and lighting environments, use of electronic and paper procedures in microgravity, and questionnaire responses to a consolidation of questions generated by HFA studies.

The electronic procedures (EPROC) experiment sought to define human factors requirements for electronic procedures of systems in space environments. A computer-based task simulating a Space Station propulsion system task was completed by one crewmember using first paper and then computer procedures. A soldering task was completed by another crewmember using paper procedures, with the desoldering portion completed using computer procedures. Results suggest that computer procedures could be used in the future in place of paper procedures with little loss in productivity. Recommendations will be made available to future designers of electronic procedures systems for manned-space missions and other related uses.

The human factors assessment light experiment (HFA-Light) represented the first time that systematic light intensity measurements were performed on the Orbiter during a mission. The crew used an exposure meter to measure the present in-flight light levels on the middeck, flight deck, and SpaceHab. Light levels measured in each of the modules met the required brightness ratios and were rated as acceptable by the crew. SpaceHab was considered "bright and cheery" with the auxiliary lights in use. Some crewmembers noted that areas along the SpaceHab outer walls were noticeably dimmer than the general or central area when the auxiliary lights were not in use. When asked to identify any problematic areas of illumination, crewmembers commented that on occassion sun shafting through the aft and overhead windows washed out the normal illumination and caused glare on the flight deck monitors and electronic displays.

The goals for the human factors assessment sound experiment (HFA-Sound) were to collect in-flight sound level measurements and to use this data in conjunction with subjective data gathered by the human factors assessment questionnaire experiment (HFA-Quest) to evaluate current Orbiter and SpaceHab acoustic conditions. Ten noise measurements were completed by the crew during the flight. Mission operations were not significantly impacted by noise during this mission; however, noise did induce fatigue and headaches in some individuals and necessitate the use of earplugs during sleep and with the ICOM, interferring with the ability to concentrate, relax, sleep, and communicate verbally.

The questionnaire study required crewmembers to supply numerical ratings and comments for assessment of the acoustic and lighting environments, tunnel design, and for the questionnaire itself. Results of the current study suggest that questionnaires offer a means of obtaining useful data, particularly if the questions concentrate on specific aspects of the interface or environment. The computer version of the questionnaire did not appear to elicit more crew comments than the written version, suggesting that use of a computer for a questionnaire should be carefully considered due to the likelihood of introducing additional time, power, and work volume requirements.

For the translation study, video was collected of crewmembers moving through the SpaceHab transfer tunnel early and late in the mission so that translation times and strategies could be characterized. Translation towards the middeck took slightly longer early in the mission. The time to translate the SpaceHab tunnel was slightly greater when equipment was being carried than when it was not, especially when the equipment was sensitive or large in volume. Design of the tunnel entrance and the placement of handholds were considered acceptable. When translating without equipment, crewmembers grasped the handholds on either side of their bodies and pulled themselves through the tunnel; however, when carrying objects they used hand push-offs beneath their body to negotiate the tunnel.

Information collected from this and previous evaluations will be incorporated into a database of space and life sciences research and used in the development of human factors standards for space. Additionally, it will be used to update the Man-Systems Integration Standards (NASA-STD-3000) and to suggest improvements in Orbiter hardware design, training requirements/procedure definition, and timeline development.

I. GENERAL INTRODUCTION

SpaceHab-1 (STS-57) was the first of six scheduled commercial middeck augmentation module (CMAM) missions seeking to offer entrepreneurial companies an opportunity to use the resource of microgravity. The SpaceHab module, which occupies about one-fourth of the payload bay, is approximately 2 $^3/_4$ meters (9 feet) long and 4 meters (13.5 feet) in diameter. It provides a shirt-sleeve working environment and contains the storage space equivalent of 50 middeck lockers—considerably over and above the number of experiments that can be carried in the Orbiter middeck alone. A modified Spacelab tunnel links the SpaceHab module to the middeck. While in orbit, the Orbiter payload bay doors remain open, exposing the padded exterior of the lab and tunnel to space, until preparation for re-entry at the end of the flight. The crew for SpaceHab was comprised of four males and two females, each of whom participated in some part of the human factors assessment (HFA) evaluation.

The HFA was one of over twenty experiments manifested on this maiden flight of the SpaceHab module. HFA consisted of HFA-EPROC, HFA-LIGHT, HFA-SOUND, HFA-QUEST, and the human factors assessment translation experiment (HFA-TRANS). The goal of HFA-EPROC was to assess the advantages and disadvantages of paper versus computer presentation for procedural tasks. The second two evaluations investigated the module's lighting and acoustic environment. HFA-TRANS sought to evaluate the design of the SpaceHab tunnel and to characterize translation through it. HFA-QUEST represented a consolidation of the in-flight questions generated by the HFA principal investigators involved in the acoustic, lighting, and translation studies.

II. HUMAN FACTORS ASSESSMENT - EPROC

INTRODUCTION

The primary concerns of human factors engineers at NASA's human factors and ergonomics laboratory (HFEL) are the investigation and evaluation of human-machine interfaces unique to spaceflight which affect crew productivity and ultimately impact mission success. The human factors assessment (HFA) was an experiment conducted aboard SpaceHab 1 (STS-57) by the HFEL. During this mission, crewmembers evaluated the design and use of electronic procedures (EPROC).

All Shuttle on-board tasks are currently performed using written paper procedures. This represents a large amount of launch weight and valuable stowage space. There are also particular problems with using paper procedures with hands-on tasks. For example, it is cumbersome for crewmembers working in a glovebox to take their hands off the task to turn a page of the procedures or to make an annotation. There are also limitations on the amount of information that can be presented in on-board paper procedures. Electronic, computerized procedures have none of these problems. The amount of information that can be made available and the capabilities that can be provided via computers to improve crewmembers' performance make electronic procedures worthy of investigation.

The goal of the HFA-EPROC experiment was to determine human factors requirements for electronic procedures systems in flight environments. Performance measures were taken for the same task using both computer and paper procedures. Advantages and disadvantages of each procedure type were noted. In addition, several automated procedures capabilities were provided to the crewmembers for evaluation. Thus, the investigation could identify the benefits of paper and the potential benefits of computer presentation, rather than just comparing the two.

The HFA-EPROC experiment consisted of two types of tasks: a computer task and a noncomputer task. The computer task consisted of a simulated Space Station propulsion system task which involved interacting with a graphical interface to configure the system. The task was performed once with computer procedures and once with paper procedures. This type of task was included because future missions could be commanded entirely via graphical software interfaces where crewmembers read on-screen procedures and then configure systems by clicking on icons and soft buttons.

The noncomputer task, any task not performed on the computer although procedures may have been displayed on the computer, consisted of a solder and desolder experiment. This portion was performed in conjunction with the SpaceHab tools and diagnostic systems - solder equipment (TDS) experiment. The solder portion was completed using paper Flight Data File (FDF) procedures, and the desolder portion was completed using computer procedures. This noncomputer task was included to collect information on the use of electronic procedures with a hands-on glovebox task. Because of the hands intensive nature of the glovebox task, voice input was one of the computer capabilities investigated.

Previous research into paper and computer procedures has been performed in the HFEL at the NASA Johnson Space Center (O'Neal 1992; O'Neal and Manahan 1990; Desaulniers, Gillan, and Rudisill 1989). Results from this research and reviews of relevant literature (Johns 1988; Kelly 1988) provided the basis for the design of the HFA-EPROC experiment.

METHOD

Subjects

One crewmember participated in the computer task and one crewmember participated in the soldering task (noncomputer task). Additional subjects and trials were not possible due to mission timeline constraints.

Apparatus and Materials

A Macintosh PowerBook 170 was used to run the custom-built electronic procedures software. The electronic procedures and the computer task display were created with Supercard. The cursor control device used was a slightly modified version of the standard PowerBook trackball.

The electronic procedures software was custom-built to investigate the usability of the interface. The display was split into halves vertically. The procedures were presented on the left-hand side; the crewmember scrolled through to complete the task. The task was completed on the right side of the display, where a simulation of a Space Station core system propulsion display was presented. The display was a direct manipulation interface where the user could click on icons representing system objects such as valves or heaters and change the parameters associated with those objects (figure 1). The software kept track of task times (between each step in the procedure), the sequence of window openings and closings, and the sequence of button presses.

The noncomputer task included the use of a voice input system (Voice Navigator software by Articulate Systems). The system was used solely to move from step to step in the procedure.

Design

The experiment used a simple within-subjects design. The independent variable was procedure type (paper vs. computer). Dependent variables were total time on task, time on subsets of tasks, error rate, and subjective ratings.

This basic design was repeated for each task type: computer and noncomputer (table 1).

Table 1. The Experimental Design

	Computer Task	Noncomputer Task
Paper Procedures	Crewmember 1	Crewmember 2
Computer Procedures	Crewmember 1	Crewmember 2

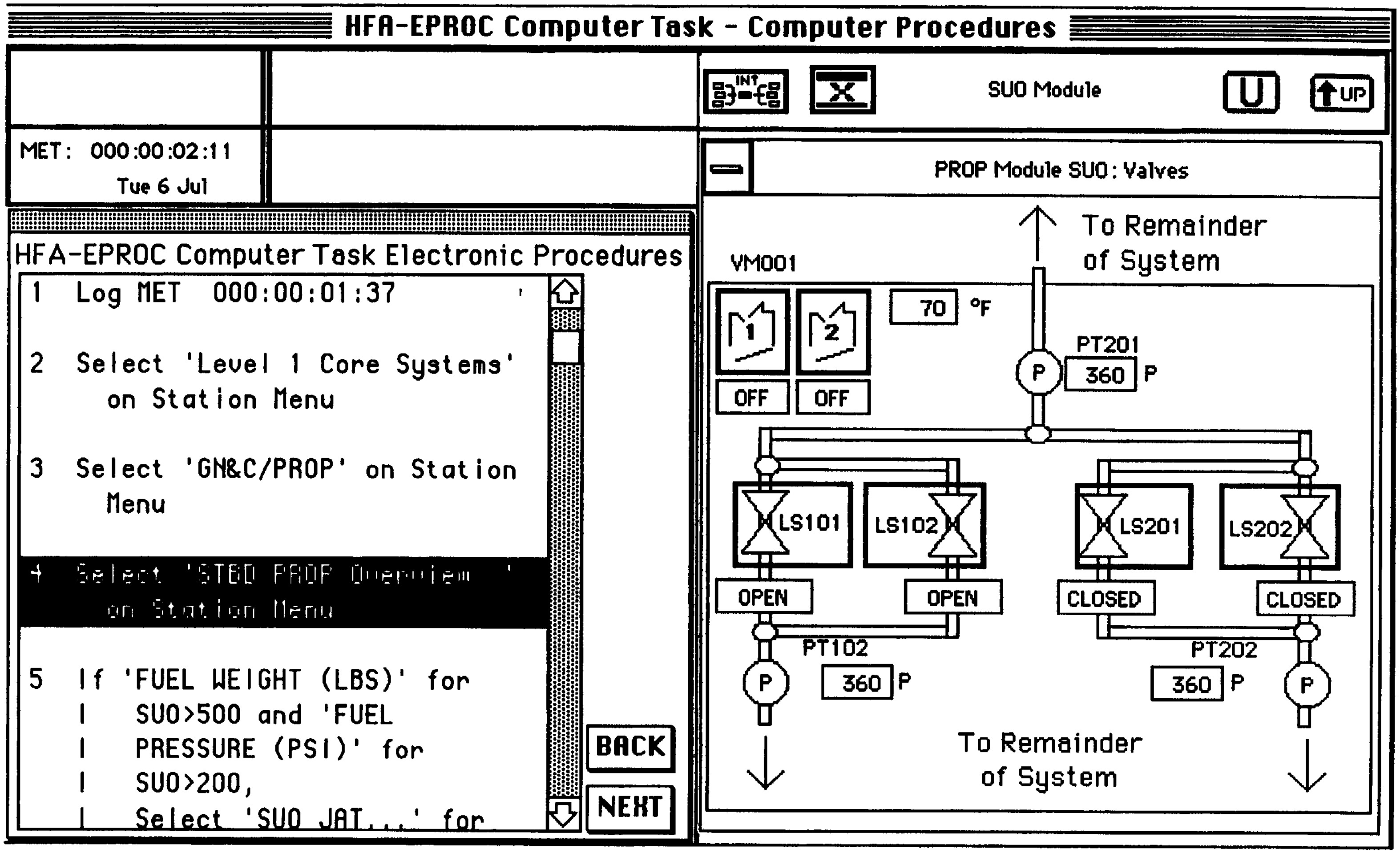
Subjective ratings were collected via a computerized questionnaire that was presented after the completion of each task. The questionnaire ratings were anchored by using 7 point Likert scales.

Procedure

The crewmembers were trained on their respective tasks during formal familiarization, hands-on, and timeline training sessions. Crewmember 1 also requested and completed several task review sessions prior to the mission. For both the computer and noncomputer tasks, the procedural information available to the crewmember was identical in the paper and computer versions of the procedures. What differed were capabilities to access the information. Table 2 summarizes these differences.

Computer Task - Crewmember 1 began each computer task session by setting up the computer in the SpaceHab compartment on either the workbench or a computer table. Setup included plugging the computer in, opening it up, and turning it on. The computer was attached to the surface of the table with Velcro. The crewmember stayed in place by using foot restraints.

Crewmember 1 first completed the computer task session while using paper procedures and then completed another computer task session while using computer procedures. Figure 1 shows the display used with computer procedures. Note that for paper procedures the left side of the display remained blank. The right side of the display remained the same for both tasks.



HFA-EPROC Computer Task - Computer Procedures

MET: 000:00:02:11
Tue 6 Jul

HFA-EPROC Computer Task Electronic Procedures

1 Log MET 000:00:01:37

2 Select 'Level 1 Core Systems'
on Station Menu

3 Select 'GN&C/PROP' on Station
Menu

4 Select 'STBD PROP Overview '
on Station Menu

5 If 'FUEL WEIGHT (LBS)' for
| SUO>500 and 'FUEL
| PRESSURE (PSI)' for
| SUO>200,
| Select 'SUO JAT...' for

Figure 1. Sample display from the SSF propulsion simulation task.

Table 2. Comparison of Features Provided With Each Procedure Type

Computer Procedures	Paper Procedures
• Immediate access to diagrams, schematics, and malfunction procedures	• Diagrams, schematics, and malfunction procedures in an appendix
• Immediate access to step details	• Step detail information in a separate table
• Notes, Cautions, and Warnings automatically displayed only when relevant	• Notes, Cautions, and Warnings printed along with procedure steps
• Current step highlighted to assist in placekeeping	• Current step not highlighted
• Placekeeping input through use of onscreen buttons	• Placekeeping possible only through manual mark-up of procedures
• Timing information tracked automatically through initial input and use of onscreen buttons	• All timing information tracked manually
• Annotations and comments accepted through available notepad	• Annotations and comments available through predefined blank lines or other markings
• Scrolling provided through onscreen buttons and manual use of scroll bars	• No scrolling facilities provided
• Voice input available for increased hands-free procedure operation (noncomputer task only)	• No voice input facility provided

Noncomputer Task - Crewmember 2 began the soldering sessions with the setup of the glovebox apparatus. While performing the computer procedures session, the Powerbook was set up and attached with Velcro to a locker to the crewmember's left in a flat upright position. The voice navigator headset was plugged in and the headset was donned.

Crewmember 2 then performed a soldering task session while using the paper procedures. The soldering task consisted of soldering some preselected sites on an electronics board while following the procedures. Next, the crewmember completed a desoldering task session on a different electronics board while using the computer procedures. The computer procedures allowed the crewmember to advance to the next step in the procedures via a voice command for hands-free operation.

Objective data was gathered for both computer and noncomputer task sessions via the computer programs, videotapes, and FDF procedure annotations. This provided baseline data on migrating from paper to computers in space. After each task session, subjective data was gathered through the use of a computer-based questionnaire program, providing data on what to include and what to avoid in the design of future electronic procedures systems.

RESULTS AND DISCUSSION

Results for the computer task are presented below and include the completion times for the task and crewmember comments. Due to timeline constraints, insufficient data was collected for the noncomputer task; thus no discussion of this task follows.

In addition to determining the overall task completion times, task times were broken down into subsets (thirds) in order to get a more granular look at the crewmember's ability to complete the task. The overall task completion time, as well as all of the individual subset completion times, was faster for the computer procedures (table 3). Formal statistical tests are not appropriate here since the data represent only a few data points from one subject. However, the consistency in trends among each of the sets of completion times indicates that there is probably a real time advantage for the computer procedures. Evaluation of the data indicated no significant errors.

Table 3. Overall and Task Subset Completion Times in Minutes

	Paper	Computer
Overall	17.42	14.83
Subset 1	5.02	3.87
Subset 2	2.98	2.02
Subset 3	9.43	8.23

Overall, the computer procedures were rated very favorably in the questionnaire. Regarding the ease of use of the computer procedures interface, the crewmember commented that "the format of the procedures was very user friendly and resulted in the task being easily performed."

The primary advantage of computer procedures over paper procedures, as identified by the crewmember, was that the current step was highlighted automatically. This released the crewmember from the burden of keeping their place in the procedures. Another comment regarding highlighting was "the procedures were very easy to read. The highlighting assisted tremendously in keeping your place in the procedures. This method assures a 'check and balance' approach to following through required procedures."

One significant recommendation made by the crew during training and ultimately incorporated into the flight version of the software was the capability to move from one step to the next via the keyboard or by trackball. The addition of keyboard redundancy allowed the crew to move on to the next step in the procedures while keeping the cursor in the working portion of the display (the task display).

Ultimately, when asked which procedures were preferred given the choice between paper and computer, the crewmember responded with "I definitely preferred the computer procedures."

The questionnaire data suggested some possible reasons for the quicker task times when using computer procedures. One comment made about using the paper procedures was "the necessity to use paper and pencil to follow through the procedures causes some overhead in zero g. The extra time necessary to clip or tether procedures in the vicinity of the work area and to ensure procedures and writing utensils are not free floating extends the time required to complete the task." Another possible reason for the time difference between computer and paper procedures could be the order of completion. The paper procedures were completed first; therefore, the task would have been fresh in the mind of the crewmembers as they completed the computer task. However, this effect should have been significantly diminished since the task had been rehearsed many times before the actual mission. Order and practice effects should have been minimal.

CONCLUSION

Because Shuttle missions currently use paper procedures, one objective was to establish the paper procedures usability data as a minimum baseline for performance while using computer procedures. The data suggest that computer procedures could be used in the future in place of paper procedures without a significant loss in productivity.

It is recommended that future versions of electronic procedures continue to offer the capability for the individual to move from one step to the next using either the keyboard or trackball. The addition of keyboard redundancy allowed the crew to move on to the next step in the procedures while keeping the cursor in the working portion of the display (the task display). These findings and findings from similar studies will enable designers to create more powerful, usable electronic procedures systems. This is especially critical since future, longer-duration missions will rely increasingly on electronic procedures since they are more easily launched, can be updated in flight, and offer automatic or on-request capabilities that are not available with paper.

To facilitate future migration to electronic procedures, performance must be at least equal to performance achieved with paper procedures. This investigation is the first step in confirmation that electronic procedures are a feasible alternative and can offer many benefits over paper presentation.

III. HUMAN FACTORS ASSESSMENT - LIGHT

INTRODUCTION

The objective of the HFA-LIGHT experiment was to determine if required lighting levels within the Orbiter and SpaceHab have been maintained in compliance with NASA-STD-3000 for performing IVA tasks and other crew operations. To accomplish this objective, the present luminance levels of surfaces within the Orbiter middeck, Orbiter flight deck, and SpaceHab were measured by crewmembers. These data were then compared with required measurements to determine if any degradation in the lighting conditions has occurred over the life of the vehicle. In addition to subjective comments on the lighting at specified locations, comments on other areas that are in need of unique lighting solutions because of problematic natural/artificial lighting were provided by the crew.

METHOD

Subjects

All crewmembers completed the light portion of the HFA questionnnaire. Two crewmembers were trained in the use of the luminance measurement equipment.

Apparatus and Materials

A handheld Minolta Spotmeter M was used to take surface readings of luminance levels from specified locations within the flight deck, middeck, and SpaceHab. Crewmember ratings and comments regarding various lighting scenarios were gathered through the use of a questionnaire.

Procedure

To measure the interior lighting levels without solar illumination, readings within the flight deck and SpaceHab were taken during a night pass. A press and hold measuring button on the spotmeter was activated to allow light to reach the meter sensor. An indicator circle within the eyepiece was focused to locate and measure the target areas. The button was released to freeze the reading on the meter's digital display and the data was recorded in the appropriate location on an illustrated diagram of the area. The luminance levels were measured and recorded in units of exposure values (EV) which were translated to the English unit of footlambert ($\frac{1}{\pi}$candela/ft^2) and the SI unit of candela/m^2 (or cd/m^2).

RESULTS AND DISCUSSION

Luminance Measurements

Within the middeck, flight deck, and SpaceHab, the preceding procedure was followed at each location shown in figures 2 through 9. These figures contain calculated luminances in footlamberts and candela/square meter along with crew notes regarding the measurement conditions.

For the measurements taken for figure 3, the crew noted that the illumination levels were relatively bright. Comments regarding the conditions during data collection (figure 4) were that there were many dark corners and that the levels were representative of nominal conditions. Data for figure 6 was gathered during nominal lighting conditions also. The crew stated that "qualitatively, SpaceHab is much better illumination-wise than the middeck."

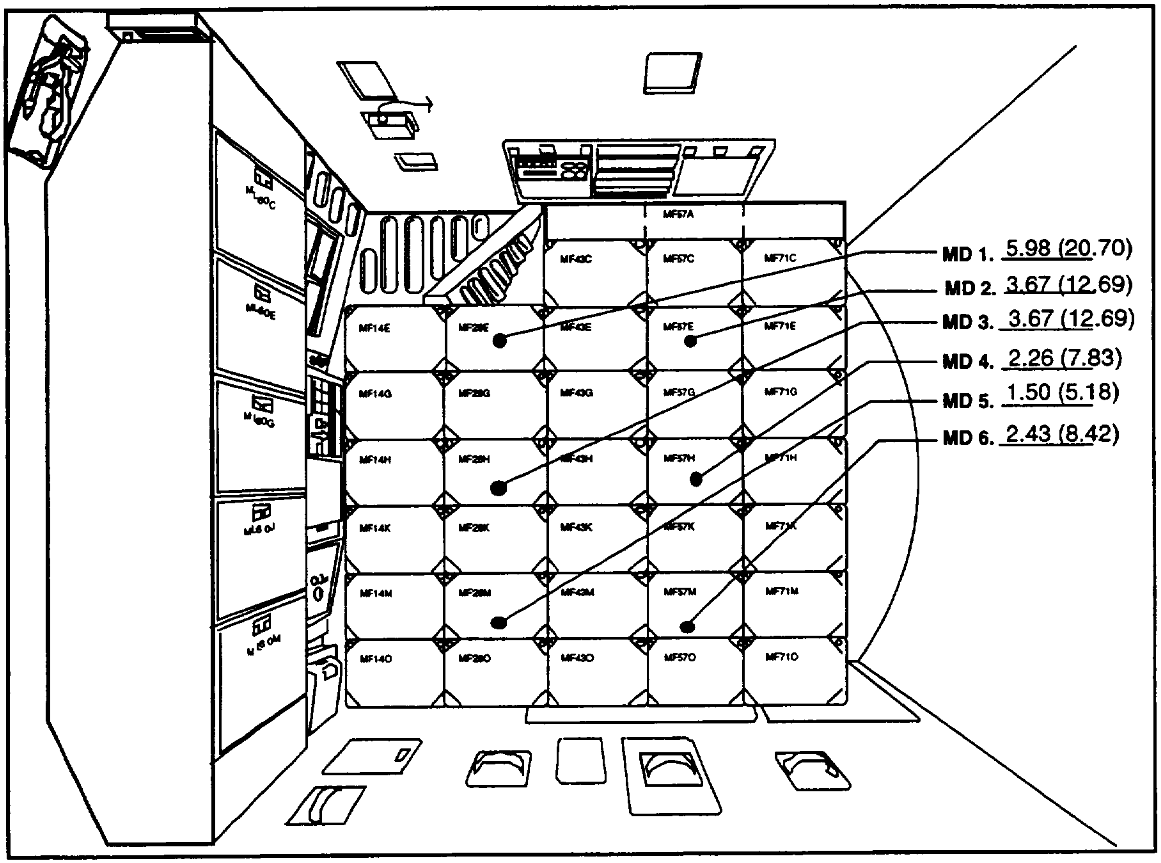


Figure 2. Middeck light measurements—forward. Units in footlamberts (candela/square meter).

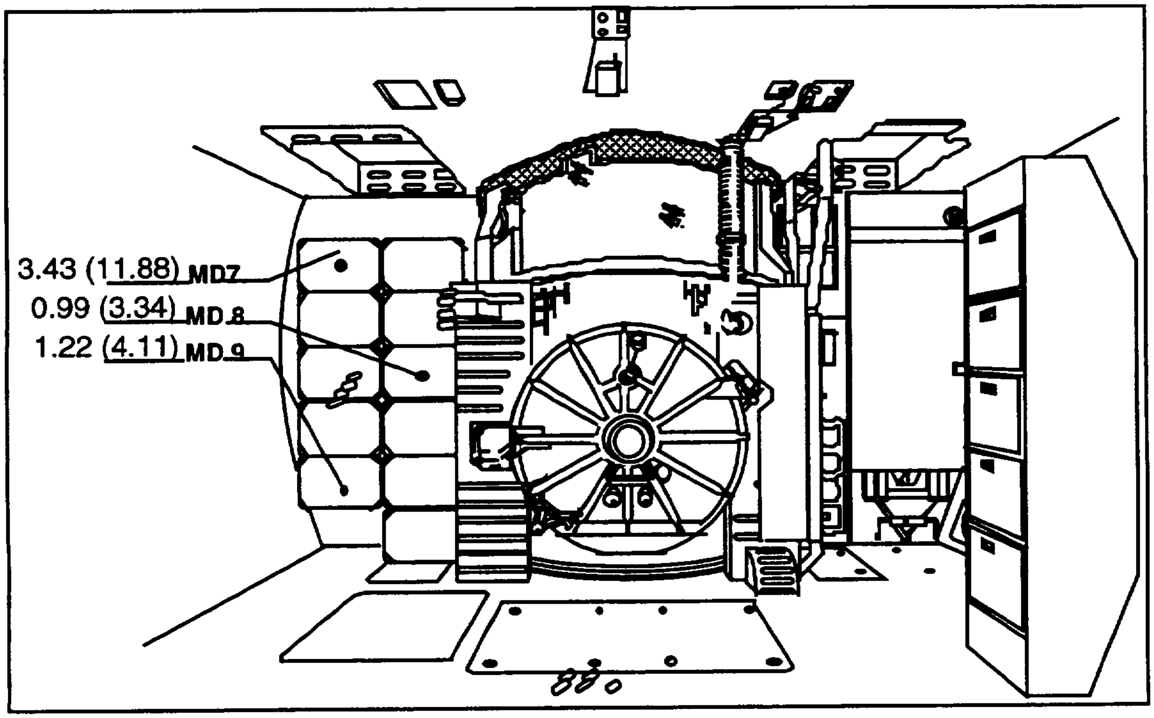
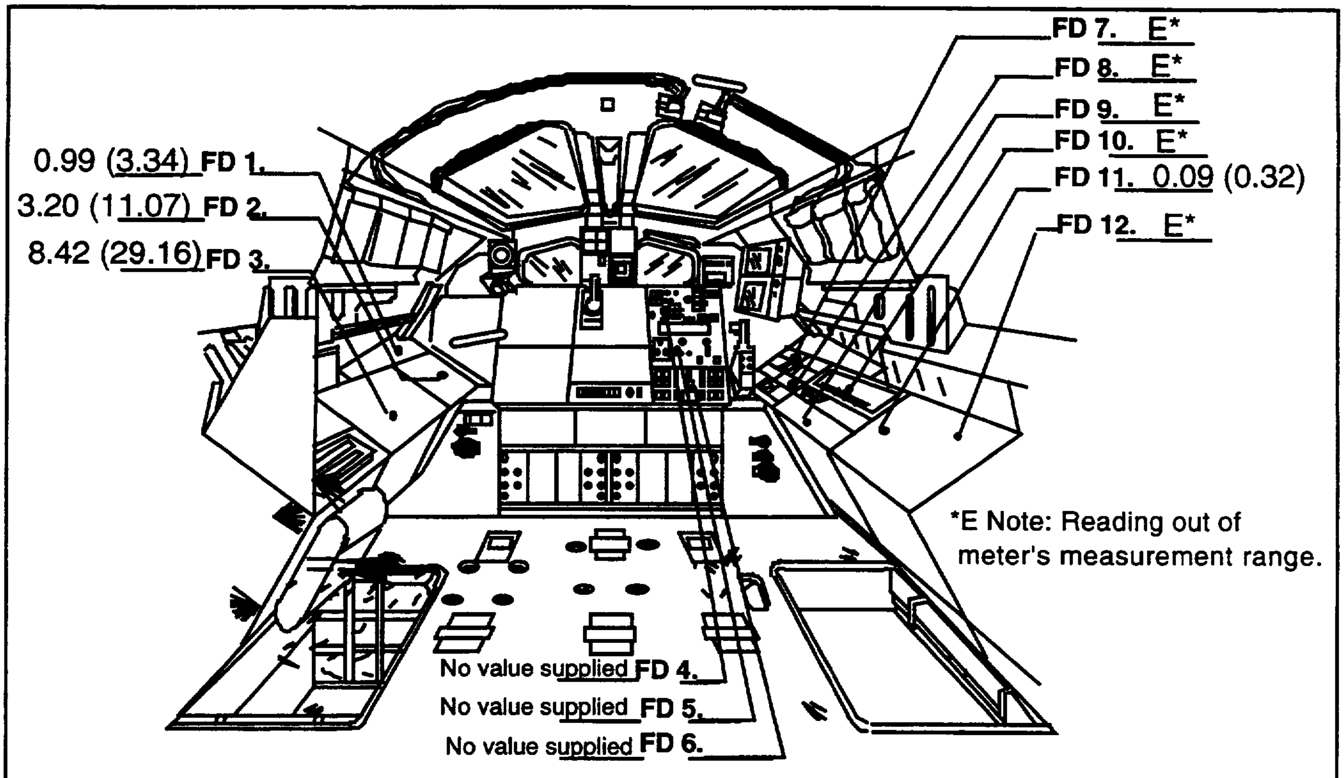
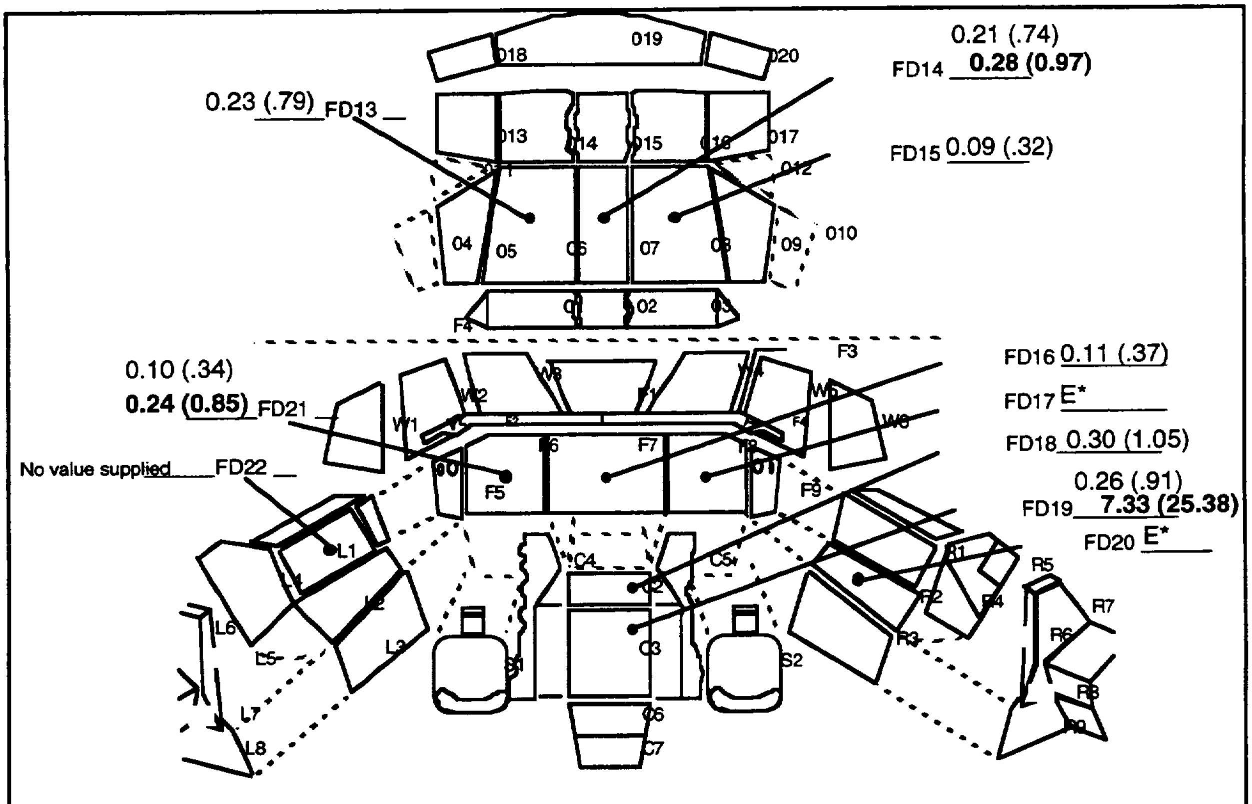


Figure 3. Middeck light measurements—aft. Units in footlamberts (candela/square meter).



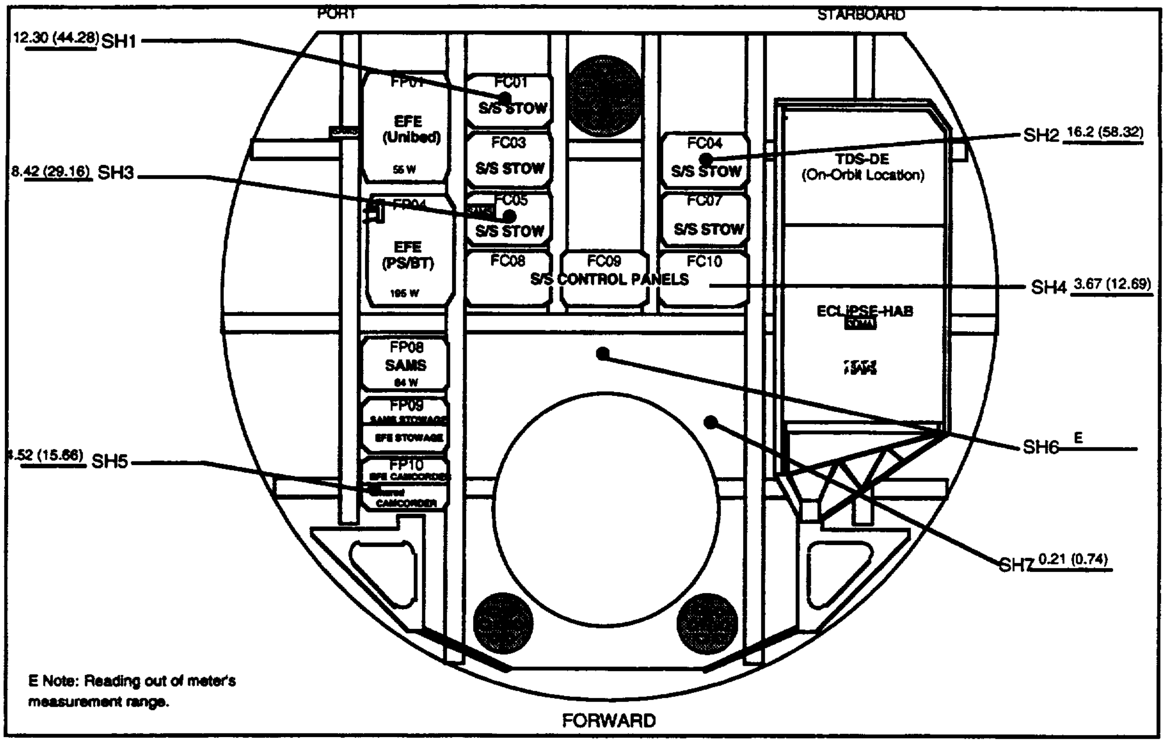
NOTE: Foward port and aft starboard floodlights "on". Aft port, overhead, and forward starboard floodlights "off".

Figure 4. Flight deck light measurements—aft. Units in footlamberts (candela/square meter).



*E Note: Reading out of meter's measurement range.

Figure 5. Flight deck light measurements—forward. Units in footlamberts (candela/square meter).



E Note: Reading out of meter's measurement range.

Figure 6. SpaceHab light measurements—forward. Units in footlamberts (candela/square meter).

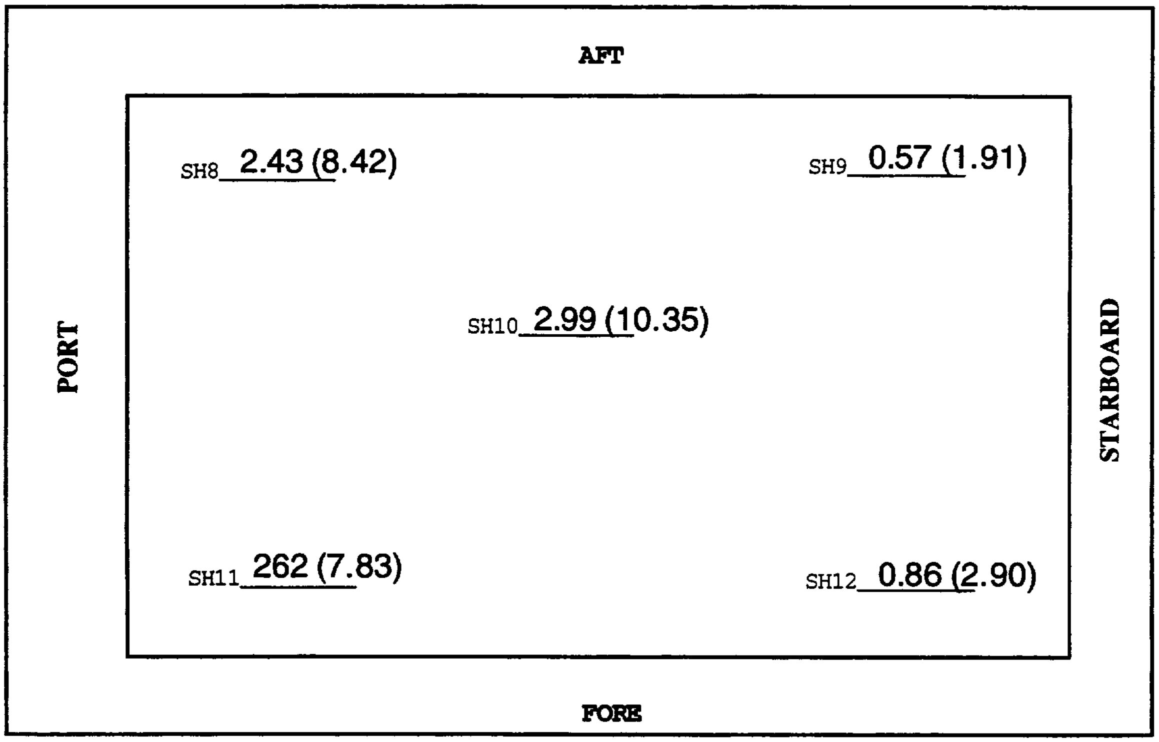


Figure 7. SpaceHab light measurements—floor. Units in footlamberts (candela/square meter).

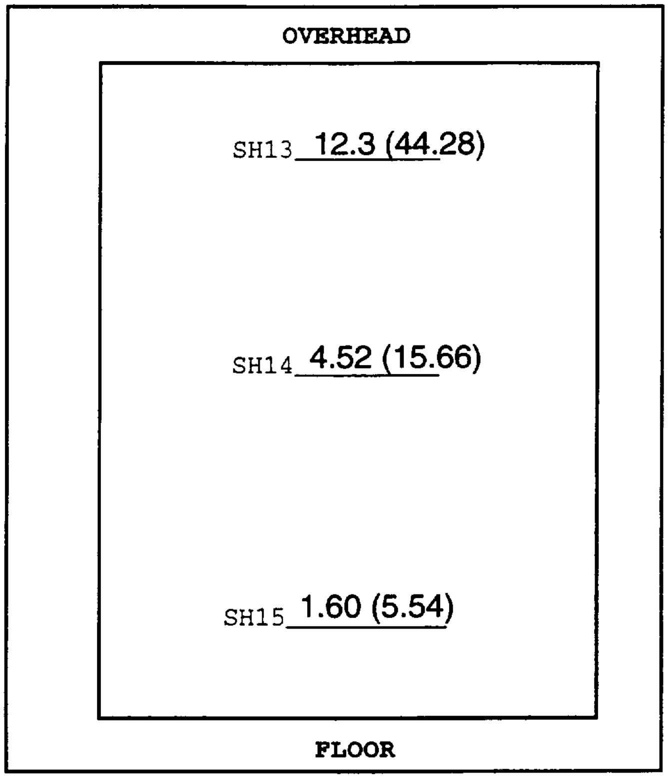


Figure 8. SpaceHab light measurements—rack surface. Units in footlamberts (candela/square meter).

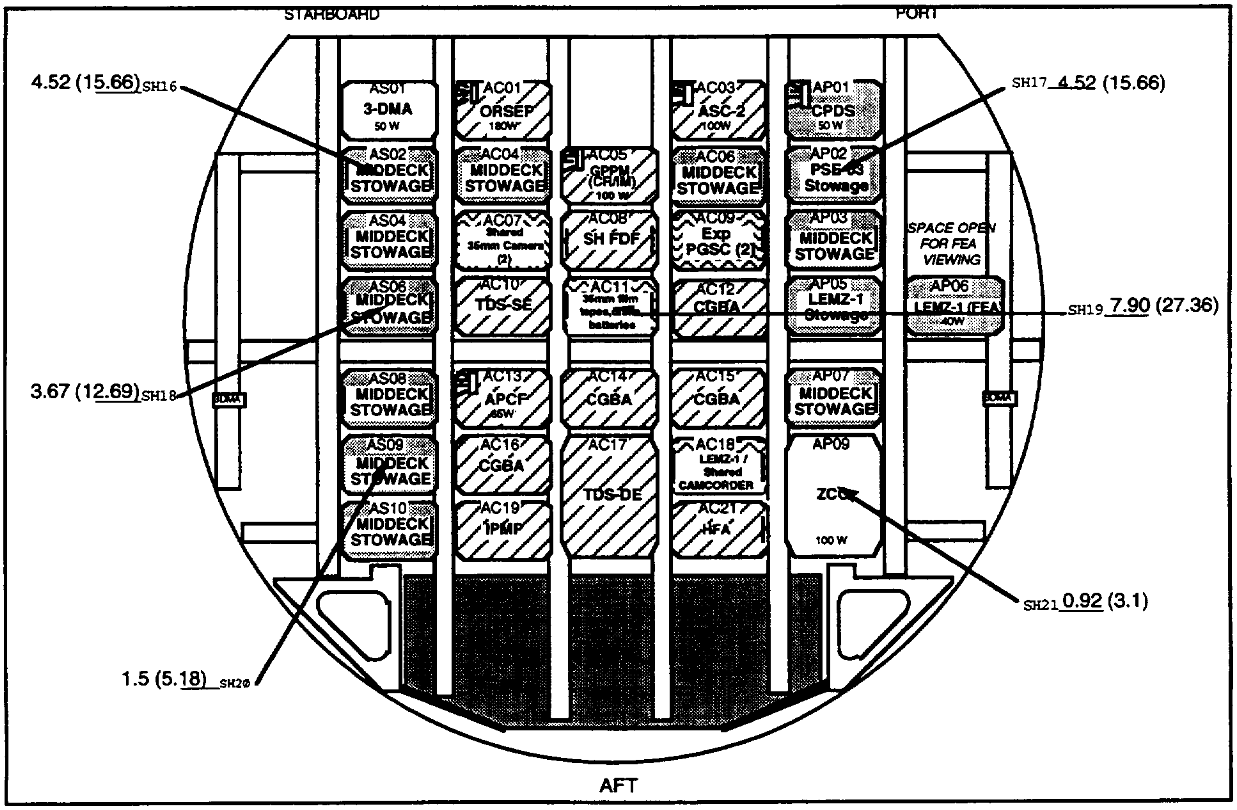


Figure 9. SpaceHab light measurements—aft lockers. Units in footlamberts (candela/square meter).

Questionnaire

The crew was asked to rate and comment on the interior lighting of the Orbiter and SpaceHab. Their responses to the nine lighting items (L1 - L9) are recorded in table 4. Responses are presented based on a randomly assigned letter (A-F) in order to maintain anonymity. Note that there is one rating scale for L1 through L4 and another for L5 through L8. Statement L9 does not have a rating but prompts the crewmember for a comment(s). If provided, crew comments are presented in table 5.

Table 4. Crew Ratings of the Lighting in Locations L1 - L9

Scale for Questionnaire Items L1-L4:

1	2	3	4	5	6	7
Completely Unacceptable	Reasonably Unacceptable	Barely Unacceptable	Borderline	Barely Acceptable	Reasonably Acceptable	Completely Acceptable

QUESTION	CREWMEMBERS A	B	C	D	E	F
L1. **Lighting** in Orbiter flight deck.	7	3*	6	6	2*	*
L2. **Lighting** in Orbiter middeck.	7	4*	6	6	4	*
L3. **Lighting** in SpaceHab.	7	6	7	6*	6	*
L4. **Lighting** in SpaceHab transfer tunnel.	7	5	6	7	5*	6

Scale for Questionnaire Items L5-L8:

1	2	3	4	5	6	7
Strongly Disagree	Disagree	Slightly Disagree	Unsure	Slightly Agree	Agree	Strongly Agree

QUESTION	A	B	C	D	E	F
L5. **Lighting levels** varied noticeably between middeck, tunnel, and SpaceHab.	6*	7*	6*	6	7	7*
L6. **Brightness ratios** across working panels varied noticeably.	5*	3	2	5*	7*	2
L7. At times **sunshafting** would wash out normal illumination.	6*	7*	7*	7*	4	FD-7* SH-1*
L8. Unique task setups blocked **lighting** for some tasks. [Indicate tasks which were affected.]	2	2	4	N/A	3	1
L9. Please comment on any other important aspects of **lighting.**	**	**	**	**	**	*

*Comment provided. See table 5.
**No rating prompted by this statement. No comment provided.

Table 5. Crew Comments for Questionnaire Items L1 - L9

QUESTION	CREWMEMBER COMMENTS
L1	**B:** *Lighting is marginal for night operations due to limited time available for dark adaptation. Sun shafting while Sun inertial was also difficult to adjust for. Sun glasses were used for RMS ops.*
	E: *Unsat for any night checklist or CRT work.*
	F: *None. Used window shades.*
L2	**B:** *Corners of the middeck were particularly dark during the EVA.*
	F: *PSE obs in upper AEM, subfloor water IPM.*
L3	**D:** *LEMZ experiment only one poorly lit.*
	F: *LEMZ (used flashlight).*
L4	**E:** *Okay for tasks required.*
L5	**A:** *MD was fine. SH's outer walls were a little dark. Transfer tunnel was dark, but it didn't matter. We had lights in it, but rarely used them.*
	B: *SpaceHab was much brighter than middeck.*
	C: *Tunnel to anywhere.*
	F: *SH brightest, then FD in sun, MD and FD at night, tunnel (we left lights off).*
L6	**A:** *Outer walls of SH were dimmer than the central part of the hab.*
	D: *Working on LEMZ FEA vs. working on PGSC.*
	E: *Flight deck checklists.*
L7	**A:** *On FD with Sun coming through the aft or overhead windows, it was difficult to sometimes see the TV monitors.*
	B: *Flight deck.*
	C: *Direct sunlight blanks all electronic displays.*
	D: *Flight deck.*
	F: *Flight deck = 7; SpaceHab = 1.*
L9	**F:** *SH auxiliary lighting really brightened up the module.*

The required space vehicle illumination levels and required brightness ratios are referenced in the Man-Systems Integration Standard NASA-STD-3000 Volume I/Rev. A in figures 8.13.3.1.2-1 and 8.13.3.2.3-1, respectively. The data retrieved from this mission is in luminance (quantitative brightness) values and, therefore, would be best evaluated using the required brightness ratio comparison between lighter surfaces and darker surfaces within the task. The ratio of 5:1 is the maximum allowed for such surfaces. According to the data collected, all light levels measured across the work surfaces in the middeck, flight deck, and SpaceHab did not exceed the required brightness ratio and were rated as nominal, completely, and/or reasonably acceptable by the crew.

CONCLUSION

The SpaceHab lighting was stated as being "much better, illumination-wise, than the middeck" by one of the crewmembers. In reference to problematic areas of illumination, crewmembers commented and agreed that sunlight shafting through the aft and overhead windows washed out the normal illumination and caused glare on areas such as the flight deck television monitors and electronic displays. In addition, some areas along the SpaceHab outer walls were stated as being noticeably dimmer than the general or central area.

It is important that required levels of illumination are maintained within the orbiter vehicles to maximize crew efficiency in performing all tasks and operations and to minimize error due to insufficient lighting. Maintenance of the levels of illumination can be verified by preflight measurements and problematic areas may be determined and resolved by routine examinations of lighting while on orbit. These objectives can be accomplished during future flights to ensure sufficient lighting is available to the crew during all IVA and EVA operations.

IV. HUMAN FACTORS ASSESSMENT - SOUND

INTRODUCTION

Noise was studied because it can severely impair human performance and, as in all manned space missions, near faultless execution of all crew tasks is essential to mission success. Humans can be adversely impacted by noise in many ways, ranging from irritability, annoyance, and sleep interference at low levels to interference with verbal communication and/or fatigue at moderate levels to temporary threshold shift (TTS) and permanent threshold shift (PTS) at more extreme levels. Noise can also reduce tolerance for frustration (Glass & Singer, 1972). In loud noise, comprehension suffers; it takes longer to read, retention of details of the passage read is poor, and writing efficiency may also be diminished (Salvendy, 1987). These and various other associated physiological, psychological, and performance effects have been noted by Shuttle crewmembers in the execution of their duties in the past.

In a survey of 33 Shuttle astronauts, researchers found that approximately 60% of respondents reported that Orbiter noise disturbed their sleep, led to annoyance, and interfered with relaxation and speech (Willshire and Leatherwood, 1985). On STS-40, 85% of the crew indicated that noise interfered with their ability to concentrate and to relax (Koros, Adam, and Wheelwright, 1992), while on STS-50, 50% of the crew noted that this had occurred (Koros, Anton S., Wheelwright, Charles D., and Adam, Susan C., 1993). Difficulty in hearing another crewmember's speech on the same deck was also noted during STS-40 and STS-50. One STS-40 crewmember considered noise to be one of the major, if not the major, contributor to fatigue during the mission. It is evident that noise conditions on board the Shuttle vary significantly between missions, warranting the study of each independently.

The objectives of the current study were to gain crewmember subjective assessments of noise levels during the STS-57/SH-1 mission; document impacts of noise upon crewmember performance; collect in-flight, one-third octave sound level measurements; interpret the subjective assessments based upon sound level measurements; compare in-flight versus postflight responses on a noise questionnaire; and make recommendations regarding noise specifications for the Space Shuttle, Space Station, and other manned space missions.

METHOD

Subjects

All crewmembers completed the sound portion of the HFA questionnnaire. Two crewmembers were trained in the use of the sound level meter.

Apparatus and Materials

Questionnaire - The HFA-Sound questionnaire consisted of 20 items which were included in HFA-QUEST. The questions were based on two questionnaires previously administered to the STS-40/SLS-1 and STS-50/USML-1 crews. The impact of noise was assessed in two ways. First, the crew rated the acceptability of the overall noise levels and the levels from various payloads. Second, they indicated whether certain physiological effects (such as fatigue, headaches, or ringing ears), psychological effects (for example, annoyance, sleep interference, or speech interference), or performance effects (such as difficulty monitoring air-to-ground loop or caution/warning alarm) occurred during the mission due to noise.

Sound Level Meter - The sound level meter used in this evaluation was a Brüel & Kjær (B & K) type 2231 modular precision sound level meter (serial number 1624553) with a B & K octave filter set type 1625 1/3-1/1 (serial number 1620800) and a B & K microphone type 4155. It was the same model flown twice previously as a DSO by the FCSD. The meter was loaded with software that automated the measurement procedure and enabled the storage of up to 10 one-third octave spectra. Figure 10 shows the meter in use during the mission.

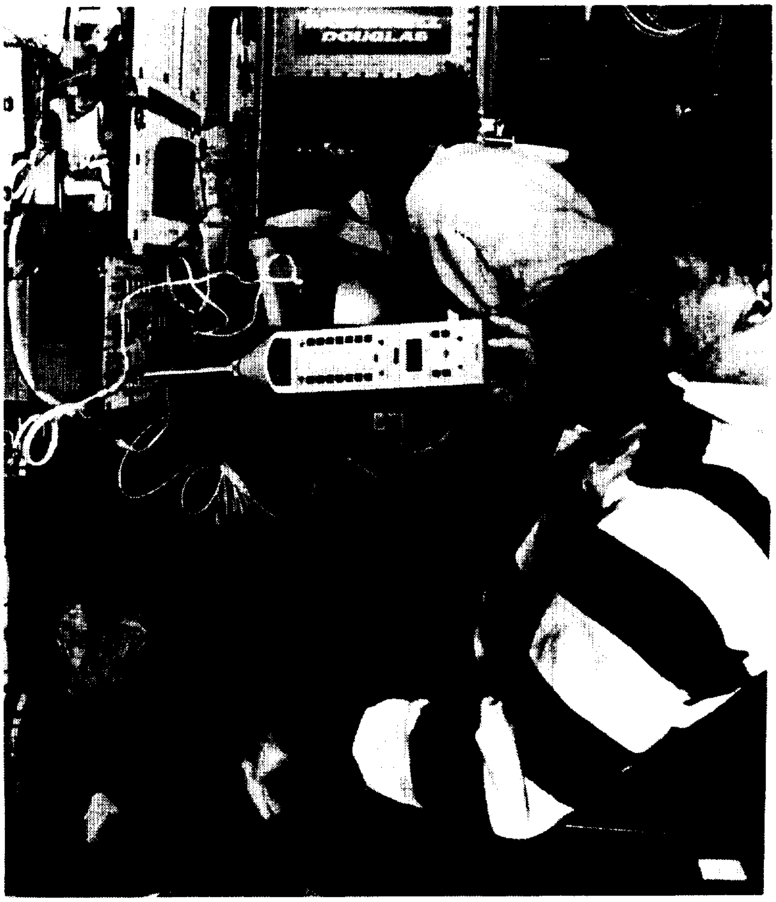


Figure 10. The STS-57 commander takes a noise measurement in the SpaceHab.

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Procedure

Questionnaire - Prior to the mission two crewmembers expressed a preference for an electronic version of the in-flight questionnaire, so one was generated. Pencil-and-paper versions were made available for the remaining crewmembers and these also served as a backup in the event that anomalies developed in-flight with the computer hardware or software. Postflight questionnaires were furnished to each of the crew after their return to JSC.

Sound Level Meter - Six sound level measurements were scheduled during periods when no major noise sources other than essential support equipment were operating. Two measurements were to be taken in the center of each of the three modules. Based on the highly reverberant nature of the Shuttles' acoustic environment, it was decided that the meters' sound incidence correction factor should be set to diffuse and the slow time weighting used (in compliance with MIL-STD-1474B specifications [DOD, 1979]). To aid the Orbiter office in its evaluation of the noise output from the EMU battery chargers, the four remaining data storage locations were designated for two measurements at the beginning and two at the end of the EMU battery charging cycle.

RESULTS AND DISCUSSION

Questionnaire

Two crewmembers completed the in-flight questionnaire on flight day 5 using the electronic version, while the remainder completed the pencil-and-paper version on the evening before landing. The responses to the first 8 items regarding the noise levels during the mission are presented in table 6. Significant range is evident within the ratings and this serves to demonstrate that susceptibility to noise is highly individualistic. This should be kept in mind when evaluating the results—it is possible to find one individual experiencing considerable annoyance as a result of noise, while another person working along side of them remains completely oblivious to it.

The overall acoustic environment was considered acceptable by the majority of the crew. However, one individual indicated that the overall noise level was unacceptable (table 6). The degree of acceptability varied based on the area and condition being rated, so each will be addressed individually.

The flight deck was considered the most acceptable of all three habitable volumes with five ratings of acceptable and only a single rating of borderline. No comments were made regarding the flight deck other than one crewmember indicating that noise on the flight deck was of "no impact."

Ratings for the middeck were split between acceptable and borderline for nominal conditions. However, for experiment operations, ratings were equally divided between acceptable, borderline, and unacceptable (2 each). It should be noted that two of the crew found levels on the middeck to be completely acceptable across both conditions. Comments by the crew suggested that the text and graphics system (TAGS) and the ergometer and galley cycling (both exercising equipment) were the sources contributing most to peak noise conditions on the middeck.

Table 6. Crew In-Flight Ratings for HFA-SOUND Questionnaire Items S1—S8

1	2	3	4	5	6	7
Completely Unacceptable	Reasonably Unacceptable	Barely Unacceptable	Borderline	Barely Acceptable	Reasonably Acceptable	Completely Acceptable

	CREWMEMBERS					
QUESTION	A	B	C	D	E	F
S1. Noise overall:	6	4	5	3	4	6
S2. Noise in the Orbiter flight deck:	7	6	7	4	5	6
S3. Noise in the Orbiter middeck during:						
a. ___nominal operations (background noise)	7	4	7	4	4	6
b. ___experiment operations (peak noise)	7	3	7	4	4	2
S4. Noise in the SpaceHab during:						
a. ___nominal operations (background noise)	6	3	5	2	4	6
b. ___experiment operations (peak noise)	6	2	5	1	4	2
S5. Noise during sleep periods:	7	3	6	4	4	7
S6. Noise from:						
a. ___Penn State experiment (PSE)	7	3	6	3	4	3
b. ___Orbiter maneuvering system (OMS)	7	6	7	4	5	2
c. ___Waste control system (WCS)	7	4	7	4	5	3
d. ___Vacuum cleaner	4	3	3	1	2	1
S7. If I were on a 30-day mission, noise levels like those on this mission would be:	6	3	6	2	4	4
S8. If I were on a 6-month mission, noise levels like those on this mission would be:	6	3	4	2	3	4

SpaceHab was rated the least favorably of the three areas. Two crewmembers found noise levels to be unacceptable even during nominal conditions (question 4a, table 6). No respondent rated the SpaceHab as completely acceptable in either condition, and for experiment operations there was one rating of completely unacceptable. The ECLSS flight experiment (EFE) was identified by most of the crew as the main source contributing to the SpaceHab noise level, though the SpaceHab fans were also identified by one crewmember. Typical comments were that the EFE was "by far the loudest experiment" and that it was "too loud—unacceptable." One respondent noted that SpaceHab "has many running motors which could give you a headache if you couldn't leave once in a while." Even the individual who rated the module the most favorably stated "SpaceHab was noisier than the Orbiter, but not too bad. You wouldn't want to sleep there though."

Noise levels during sleep periods were considered acceptable by three of the crew (question 5, table 6), two of whom noted that they wore earplugs. The range of responses regarding the acceptability of noise levels for sleep appears to be more likely a function of individual sensitivity to noise and not one of location—ratings did not seem to be based on whether the individual slept in the middeck, flight deck, or airlock. Supporting this assertion is the statement by one crewmember that "I slept in the middeck the first two nights, and the flight deck thereafter. Both were about the same." The sources responsible for interruption of sleep are presented below.

The sixth question on the questionnaire (table 6) addressed the acceptability of specified sources that were considered likely to be problematic. Though three of the crew indicated that the Penn State experiment in the SpaceHab was unacceptable, all three responses fell in the barely unacceptable category, suggesting only marginal improvement would be required. Noise levels induced by the Orbiter maneuvering system jet firings were considered acceptable by four of the crewmembers, partly because it fires "for such a short time." The waste control system was also rated favorably with only one response of unacceptable, and this fell in the barely unacceptable category. In fact, one crewmember found the "WCS noise level was nonobtrusive." By far the source rated as least acceptable in terms of its acoustic output was the vacuum. Two crewmembers found it completely unacceptable, and the most favorable rating it received was borderline (by just one person). Comments also identified the vacuum as being too loud. Though this source does not operate for extended periods of time, based upon the current crew's reaction, there appears to be some need for reduction in its operating noise level.

As can be seen in the final two items in table 6, crewmember ratings were equally split between unacceptable, borderline, and acceptable when asked whether the noise conditions they experienced during this mission would be acceptable for a 30-day mission. One comment indicated that though the individual had rated the level as borderline, they would downgrade it to unacceptable if EFE was operating. When asked to rate the acceptability of the current mission noise levels for a 6-month mission, half of the crew indicated that they believed they would find the levels to be unacceptable. Again, the same crewmember mentioned previously indicated that if EFE was operating they would consider the noise level unacceptable and not borderline as they had rated it. As one crewmember stated, it is "hard to predict, but you'd tire of the noise."

Length of mission appears to play a major role in the acceptability of noise conditions—3 crewmembers rated the levels experienced as acceptable for the current mission length. However, only one believed the levels would be acceptable for six months. These responses indicate that reduced acoustic levels are advised as mission durations are increased. Items S9 through S19 investigated the various physiological, psychological, and performance effects most likely to be caused by prolonged noise exposure. Crewmember responses to these questions are presented in table 7.

Questions sixteen and seventeen were concerned with the physiological effects of noise. Three of the six crewmembers were not awakened by noise, but comments indicated that at least two of them had used earplugs during sleep periods. In the words of one astronaut it was "difficult to sleep without earplugs or headphones." All three crewmembers who reported sleep interference due to noise indicated TAGS as the source, and only one of them named any additional sources. One crewmember stated, "TAGS woke me up almost every night about two hours prior to wakeup." The individuals who slept in the airlock also indicated that they were awoken by TAGS, and that this occurred three to four times per night in their estimation. The two additional sources noted as being responsible for interruption of sleep were the application specific preprogrammed experiment culture (ASPEC) and the Penn State experiment (PSE).

Table 7 shows that no individual reported experiencing ringing ears. A total of three crewmembers, however, experienced fatigue or headaches—one of whom experienced both. No single source was directly implicated, though the individual who experienced both symptoms stated, "I had to turn (the) A/G and ICOM loops up in order to hear them, resulting in an overall increase in noise level."

Table 7. Crew Ratings for HFA-SOUND Questionnaire Items S9—S19

QUESTION	CREWMEMBERS					
	A	B	C	D	E	F
	Percentage of Time					
S9. During what percentage of the mission did you have difficulty hearing another crewmember's speech without the use of an intercom:						
a. between FD and MD?	50	95	100	80	90	90
b. on the same deck?	0	0	20	20	30	20
c. between MD and SH?	100	100	100	100	100	100
S10. During what percentage of the mission did you have to raise your voice to be heard by another crewmember:						
a. between FD and MD?	50	95	10	80	90	90
b. on the same deck?	25	0	10	20	30	20
c. between MD and SH?	100	*	100	*	*	*
S11. During what percentage of the mission did noise interfere with your ability to concentrate in the:						
a. Orbiter	0	0	0	10	20	10
b. SpaceHab	0	0	0	30	N/A	10
S12. During what percentage did noise interfere with your ability to relax in the:						
a. Orbiter	0	90	0	N/A	40	N/A
b. SpaceHab	0	N/A	0	N/A	N/A	N/A
S13. During what percentage of the mission did noise interfere with your ability to monitor the a/g loop in the:						
a. Orbiter?	0	30	0	20	30	20
b. SpaceHab?	0	30	0	40	30	30
S14. During what percentage of the mission did noise interfere with your ability to monitor the speaker in the:						
a. Orbiter?	0	30	0	20	30	20
b. SpaceHab?	0	30	0	40	30	30
	Yes or No					
S15. Was any source/payload particularly loud or irritating? If so, please state the source(s).	Y	Y	N	Y	Y	Y
S16. Did noise wake you up? (Please state the source)	N	Y	N	Y	Y	N
S17. Did noise result in: a. fatigue?	N	Y	N	N	Y	N
b. headaches?	N	N	Y	N	Y	N
c. ringing ears?	N	N	N	N	N	N
S18. Did noise cause you to have difficulty hearing a caution or warning alarm?	N	N	N	N	N	N
S19. Did noise interfere with your performance on a task? Briefly explain when and how it interfered.	N	N	Y	N	Y	Y

*No rating prompted by this statement.

The crew was asked whether various psychological effects had occurred (questions 11, 12 and 15, table 7). Half of the crew noted that noise had interfered with their ability to concentrate while in the Orbiter at least a portion of the time. Percentages ranged slightly higher in the SpaceHab. One individual stated that although they had reported impaired ability to concentrate 10% of the time, they would have increased this to 50% had EFE been operating. It should be noted that three crewmembers reported no such interference in any location. The ability to relax was compromised by noise levels in two individuals (question 12). The rating of 90%, though extremely high, represents the experience of crewmembers whose duties required them to remain in SpaceHab much of the time. The majority of the time this individual spent in the Orbiter was during sleep periods, at which time they found it difficult to relax enough to sleep due to the noise levels.

Crew performance is critical to mission success so, in addition to evaluating the physiological and psychological effects of noise, several items concentrated on the area most likely to be compromised in a noisy environment—verbal communications. Two questions were also asked regarding the ability to hear caution and warning alarms, and the occurrence of task interference.

Based upon responses to item b in question 9, it is apparent that crewmembers did experience some loss in the ability to hear another crewmember on the same deck (when not using an intercom). This is significant since it necessitates electronically aided voice communications in order to avoid loss of information. Beyond disrupting potentially critical information, noisy environments also require individuals to raise their voice, contributing to fatigue. Five of the six crewmembers indicated that during unaided communications, they were required to raise their voice between 10% and 30% of the time in order to be heard by another crewmember in the same module (question 10b). Only one astronaut stated that they never had to raise their voice in order to be heard on the same deck. The need to raise their voice was likely a contributing factor leading two crewmembers to report noise induced fatigue (table 7). Responses on items a and c in questions 9 and 10 suggest that no task should rely upon unaided communications between modules.

Another significant responsibility of Shuttle crewmembers is monitoring the A/G and ICOM communications loops. In response to items 13 and 14, four individuals indicated that they had experienced interference monitoring the a/g loop and speaker. One crewmember reported finding it necessary to use the speaker and microphone in the Orbiter and SpaceHab even during nominal operations. Such conditions could be expected to impact crew timelines, hamper mission operations, and result in increased frustration due to the need for repeats.

No crewmember reported difficulty hearing a caution or warning alarm. Half of the crew reported noise induced task interference (item 19). In each case the noise represented speech, either from other crewmembers or from the loudspeaker/headset. It is unlikely that much can be done in regards to this source of task interference since researchers in the field of psychoacoustics have shown that when listening to speech, the introduction of irrelevant speech (even if it is in the form of nonsense syllables) significantly undermines the ability of the individual to accurately discern the source of interest.

Sound Measurements

The current acoustic noise limits for the Orbiter, 63 dBA on the flight deck and 68 dBA on the Orbiter middeck, are presented in section 3.4.6.1.3. of the Orbiter Vehicle End Item Specification (OVEI) (NASA, 1986). Since the SpaceHab module interfaces directly with the middeck, it was required to comply with the middeck module specifications contained in NSTS-21000-IDD-MDK Rev. A (NASA, 1992). This limit is identical to the middeck specification contained in the OVEI.

All ten scheduled noise measurements were completed during the flight. The overall A-weighted sound pressure level was calculated for each measurement and it is presented in table 8 in conjunction with the acoustic limit for the module in which the measurement was taken. The column titled Measured Value provides the A-weighted sound pressure that was automatically collected by the meter upon completion of its sweep through each of the one-third octave band filters and represents a two-second snapshot of the overall level.

Table 8. Comparison of Measured and Calculated Overall A-Weighted Values for STS-57 Against the Applicable Acoustic Specification

			Overall A-Weighted Decibels		
Measurement Location (Memory Number)	MET	Condition (Primary Noise Source)	Measured Value	Calculated Value	Acoustic Limit
Flight deck, Center (0)	4/21:37	Nominal Operations (ECLSS, SAREX)	72	64	63
Flight deck, Center (1)	5/5:26	Nominal Operations (ECLSS, A/G)	62	62	63
Middeck, Center (6)	5/0:51	Nominal Operations (ECLSS)	63	66	68
Middeck, Center (7)	5/5:15	Nominal Operations (ECLSS)	62	62	68
SpaceHab, Center (4)	4/21:53	Nominal Operations (ECLSS, Fans off)	63	76	68
SpaceHab, Center (5)	5/5:20	Nominal Operations (ECLSS, Fans on)	66	78	68
Middeck, Center (8)	4/21:42	EMU Battery Charging Cycle	67	63	68
Middeck, 1' from MF28E (9)	4/21:47	EMU Battery Charging Cycle	61	70	68
Middeck, Center (3)	4/22:07	EMU Battery Charging Cycle (C/W alarm)	71	69	68
Middeck, Center (2)	4/23:16	End of EMU Battery Charging Cycle	66	69	68

Unlike the two previous missions on which this meter was manifested, many of the measured and calculated A-weighted sound pressure levels exhibit considerable discrepancy (as much as 13 decibels). It is highly improbable that the marked differences evident between the values is due to the random nature of the acoustic environment alone. The magnitude of the variances encountered during some measurements (particularly those in SpaceHab) suggest that in some cases the difference is likely to be the result of changes in the acoustic environment itself (i.e., short-term or sporadic noise sources such as verbal communications, equipment cycling, etc.). For this reason each measurement must be evaluated independently. The results and discussion will be presented for each module.

The two flight deck noise measurements were collected in the center of the module. The acoustic levels in the center of the flight deck were close to 63 A-weighted decibels, equivalent to the module limit. The A-weighted value of 72 dBA obtained during the first measurement (location number 0 in table 8) is believed to significantly overestimate nominal conditions on the flight deck. Octave band sound pressure levels for both sets of measurements on the flight deck displayed considerable uniformity, with an average difference of only 2.25 decibels across all frequencies. Therefore, these are believed to be good estimates of the module's noise level during the mission. Both the overall A-weighted and octave band acoustic specifications for the flight deck appear to have been met. Only one exceedance was common to both sets of octave measurements (at 1k hertz), and it was so slight that it is within the range expected from variances in the measurement process itself.

Six sets of measurements were collected on the middeck. The prime area of interest for this evaluation is the data points taken during nominal operations (memory numbers 6 and 7). Data from the four measurements obtained during the EMU battery recharging cycle is presented in the table for information purposes only and will not be addressed in the current paper. Measurements 6 and 7 exhibited much uniformity. Differences between the two sets of data across all octave band frequencies averaged just over 2.5 decibels, with the largest difference (6 decibels) occurring at 500 hertz. This frequency represents the only point at which the middeck module limit was exceeded and since the exceedance was evident in only 1 data set, it is believed to have been the result of a short-lived noise source. The middeck acoustic limit appears to have been met for all frequencies. The measured and calculated A-Weighted values for measurement number 6 are in perfect agreement. Taking this into consideration, along with the uniformity apparent between the two sets of frequency data, it is believed that the Middeck noise level during nominal activity was around 62 dBA, well within the acoustic specification of 68 dBA.

By far the measurements exhibiting the most significant variances were those collected in the SpaceHab module. Crew notes in the Flight Data File serve to elucidate differences between the conditions during the data collection. Measurement number 5 was taken when both SpaceHab fans were on and the CGBA and TDS experiments were in progress, while number 4 was taken with EFE and both SpaceHab fans operating. Further analysis of this data suggests that the environment most likely did not represent a constant noise condition as required by this and all acoustic analyzers utilizing a step filter. This concern is raised by the large differences within each measurement when the overall and A-weighted values are compared (Table 10): 14 decibels for measurement 4, and 12 decibels for measurement 5. However, since the measured A-weighted values represented the most conservative data, exhibited relatively minor differences, and returned a higher value when both fans were on rather than off (63 dBA verses 66 dBA), they are believed to represent the best guess of the overall noise level in SpaceHab during nominal activity. The data collected in this module exhibits so much diversity that it cannot be determined with any certainty whether the acoustic specification for this module was met or not.

CONCLUSION

Mission operations were not significantly impacted by noise during this mission. However, because of the noise crewmembers were required to use earplugs during sleep; to use the ICOM while on the same deck; reported interference in the ability to concentrate, relax, sleep, and communicate verbally; and some individuals reported noise-induced headaches and fatigue. The overall acoustic environment received mixed ratings from the crew. Three crewmembers found the noise levels acceptable. However, only one crewmember believed the noise level would be acceptable if endured for six months.

The flight deck was considered the most acceptable of all three habitable volumes, still one individual rated it as borderline. Sound meter measurements suggested that acoustic levels on the flight deck were approximately 63 dBA, equivalent to the module limit. The level most likely remained relatively constant since no experiments were contained or deployed in this volume. During nominal operations half of the crew found the middeck noise level to be acceptable, the remainder rated it as borderline. Ratings were a little harsher during experiment operations. The equipment noted as noise sources included the TAGS, the ergometer, and the galley pumps. Middeck noise levels during nominal activity were approximately 62 dBA. SpaceHab was rated the least favorably of the three modules. Two crewmembers rated noise levels as unacceptable during minimum background noise conditions and three during experiment operations. EFE and the SpaceHab fans were identified as the major sources. Sound level measurements suggested nominal operations may have ranged between 63 and 66 dBA; however, the data exhibited dramatic variance and proved to be inconclusive. It was recommended by one crewmember that CMAM continue to request that the fan clamps be loosened once in orbit because the procedure made a marked improvement in the SpaceHab acoustic environment.

Crew comments indicate that the equipment most in need of acoustic reduction efforts are the vacuum cleaner and EFE. Noise reduction efforts were also recommended for ASPEC. Reduction in the operating level of the TAGS is desirable if its operation cannot be limited to time periods outside of those allocated for sleep.

V. HUMAN FACTORS ASSESSMENT - QUESTIONNAIRE

INTRODUCTION

An important element of spaceflight human factors assessment is the data collection methodology. Scheduling constraints and crew timelines are precious resources which must be shared among the various flight experiments. It is therefore imperative that efficient and timely data collection methodologies be developed and evaluated. The human factors assessment questionnaire (HFA-Quest) was one such experimental methodology evaluated on Spacehab-1. A portable computer was used to electronically administer a human factors assessment questionnaire. In the past, questionnaires have been completed in a written format using paper or were voice recorded. The concept of an electronic questionnaire was explored as a possible means of eliciting/acquiring more explicit comments from the crew. The concept was similar to the HFA-EPROC electronic questionnaire. The questionnaire was subdivided into four sections, each addressing noise, lighting, tunnel translation, and general human factors workplace issues.

METHOD

The questionnaire was administered using a portable Macintosh PowerBook 170 computer. Prior to the mission, crewmembers were trained on the use of the software, setup, and computer backup procedures. Individual questionnaire files were created for each participating crewmember. To launch the questionnaire, crewmembers simply double clicked their assigned file name. Precautions were taken to minimize incorrect entries by disabling unnecessary commands and key functions, and by providing user messages when needed. Much of this control was achieved by using HyperCard™ to customize the user interface and control features. Bold type lettering and underlined text was used to emphasize keywords and special instructions. In addition to entering comments, crewmembers were asked to make one of the following inputs: (1) a 7-point scale rating, (2) percentage estimate, or (3) a yes/no response. The HFA-Quest software also created a separate file which tagged the start and end times for the purpose of comparing timeline constraints to actual completion times.

RESULTS AND DISCUSSION

Due to scheduling difficulties, only two crewmembers completed the computerized questionnaire. The remaining crewmembers, however, were able to complete the questionnaire in written format. Copies of the questionnaire were transmitted to the crew via the thermal and graphics system (TAGS) during their extended stay in orbit. Table 9 summarizes the rating inputs obtained for the general human factors questions regarding workplace design issues.[1] With the exception of the single borderline response, most crewmembers rated their working area and restraint device as being acceptable.

Table 9. STS-57 Crew Responses to General Workplace Design Issues

	Number of Responses		
Question	Unacceptable	Borderline	Acceptable
1. SpaceHab workbench as deployment area/surface			4
2. SpaceHab rack/locker faces as an ad hoc deployment area/surface		1	5
3. Foot restraints in SpaceHab in relation to your stability			6
4. Foot restraints in SpaceHab in relation to your comfort			6

The SpaceHab workbench and foot restraints were given positive ratings. The workbench design consisted of a work surface secured to the locker/racks by two extending diagonal poles. The

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[1] Sound, lighting, and translation questionnaire responses are discussed in each respective section.

questionnaire comments did not mention the design efficiency of the workbench. However, during the postflight crew briefing, crewmembers noted the workbench lacked horizontal support causing the workbench to sway from side to side. Comments regarding the SpaceHab indicated that because they were equipped with Velcro, the rack and locker faces were used more extensively as temporary devices than as a deployment area/surface.

Questions 3 and 4 contain comments regarding the foot restraints designed for the TDS soldering experiment. As evident from table 9, the restraint system was rated completely acceptable by all six crewmembers. The TDS foot restraints design concept differs significantly from the standard foot loops. Although the crew did not make specific design comments in the HFA-QUEST, during the postflight briefing several design issues were discussed. For example, shorter stature crewmembers felt the foot restraint needed some forward and backward adjustability. Others felt the bulky design was better suited for fixed workstations versus use as a portable unit. Nevertheless, crewmembers agreed the TDS foot restraint was the preferred device over the conventional foot loops in terms of stability and comfort.

The last HFA-question asked crewmembers to rate the use of the Macintosh Powerbook as a data collection tool and provide an estimated completion time. For the most part, the use of the computer was thought to be adequate. One crewmember, however, commented voice recording would have been faster. Both crewmembers using the computer stated it took them approximately 40 minutes to complete the questionnaire electronically. These estimated completion times could not be compared to the actual start and stop times due to postlanding logistics difficulties in retrieving the data files. Time estimates from the remaining crewmembers who completed the questionnaire in written format indicated it took approximately 30 minutes. This is a timesaving of 10 minutes, which seems to imply the use of a computer may introduce additional overhead.

CONCLUSION

Questionnaires provide a means of obtaining supporting data and crew comments particularily when related to quantitative studies. More importantly, however, is the design of the questionnaire content and structure. The SpaceHab crew briefing helped to identify areas in which the HFA-Questionnaire can be improved (e.g., the inclusion of more specific design and work volume related questions). The implementation of a questionnaire is an important factor in space applications. Timeline restrictions and available working volume are issues which must be considered. The use of a computer did not appear to elicit more crew comments than did written responses. Furthermore, it appears that using a computer may introduce additional overhead, both in terms of timeline and required work volume. This becomes critical when there are scheduling delays, as is evident from the crew briefing discussion on the HFA-EPROC study. The combination of an overburdened timeline and on-going experiments resulted in no place to attach the computer and no foot restraints. This particular problem resulted in lost data. Similar scheduling and timeline difficulties were responsible for only two crewmembers completing the HFA-Quest electronically.

VI. HUMAN FACTORS ASSESSMENT - TRANSLATION

INTRODUCTION

The SpaceHab tunnel, or the Spacelab transfer tunnel adapter, connects the Orbiter middeck to the SpaceHab space research laboratory. The tunnel is the only way for the crewmembers to transfer between these two modules. It is a cylindrical structure providing a total travel distance of approximately 2.93 meters (9.6 feet) from middeck to SpaceHab. Figure 11 shows dimensions and layout of the SpaceHab tunnel (CMMPO, 1992). The human factors assessment (HFA) - translation experiment addressed the SpaceHab tunnel and hatch design in order to document the crew translation and equipment transfer times as well as the techniques used during these processes. This evaluation was a follow-up to earlier translation studies manifested on STS-40 and STS-47 as detailed supplementary objectives.

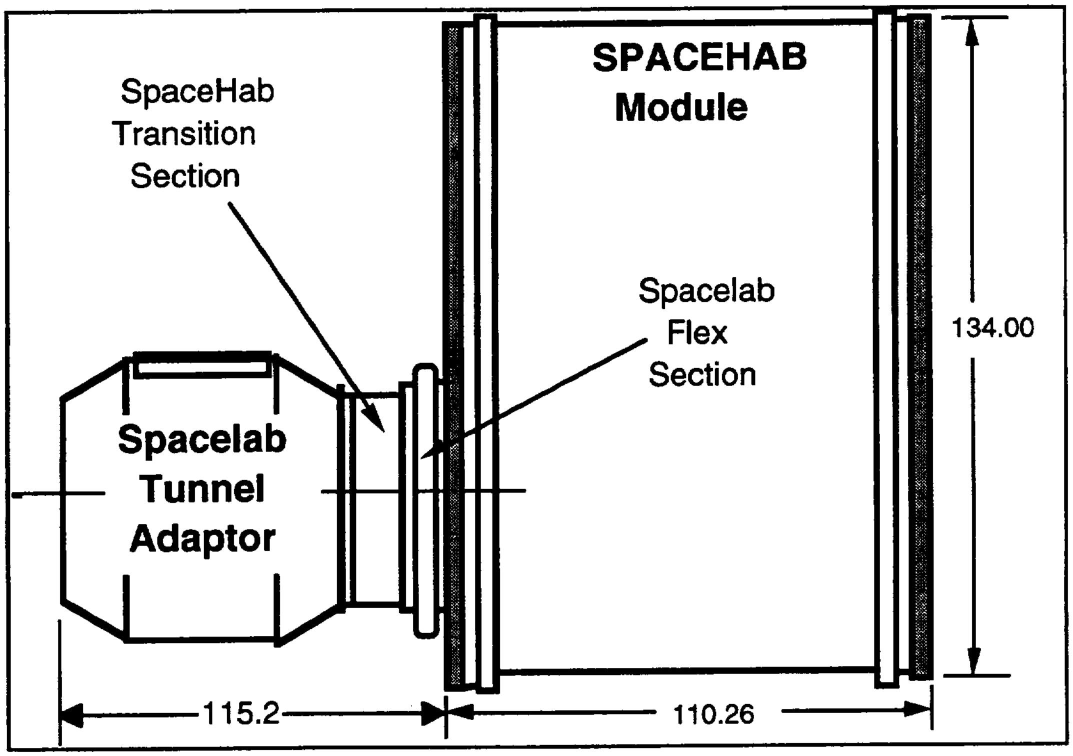

Figure 11. The SpaceHab tunnel.

METHOD

Subjects

All crewmembers completed the tunnel translation items in the HFA questionnaire. Tunnel translations of five crewmembers were observed via video collected in flight.

Apparatus and Materials

The equipment involved in this study was two 8 mm camcorders which videotaped the tunnel translations, a TV monitor and VCR used to monitor these videotapes to capture the translation times and techniques, and an electronic or pencil-and-paper questionnaire completed by the crew.

Procedure

The camcorders which recorded the crew translation were positioned in the SpaceHab, with one pointing toward the tunnel entrance and the other pointing toward the tunnel interior. Video recordings of crewmembers moving through the SpaceHab transfer tunnel early (flight day 1) and late (flight day 5) in the mission in conjunction with subjective data gathered by HFA-Quest were used to determine translation times and techniques used during the STS-57 mission. All crewmembers were familiarized with the objective and the approach of the translation study prior to the mission. Following the mission, a debriefing session was held to review the crew responses and comments.

The translation time was calculated by recording the time when any part of a crewmember's body entered the tunnel and subtracting this value from the time when the crew was completely out of the tunnel. These translation times were calculated for five of the crewmembers across different conditions: (1) whether equipment was carried or not and (2) whether the crewmember was going toward the middeck or SpaceHab. It should be noted that the number of translations per condition and the types of equipment carried were not controlled. Therefore, the questionnaire responses and translation times were computed and analyzed using descriptive statistics.

RESULTS AND DISCUSSION

Results show that rate of translation was slightly affected by the direction of travel. It was observed at the beginning of the mission that the crew took longer to translate from the SpaceHab to the middeck, than to translate from the middeck to the SpaceHab. Late in the mission, there were no such translation time differences. The crewmembers commented that it was easy to bump their head or back when entering the SpaceHab. It was noted that the footloops in the middle of the SpaceHab floor and handrails on the aft lockers helped for stopping. Overall, the translation time early in the mission was greater than the translation time late in the mission, as expected. The equipment transfer time was slightly greater than the crew translation time, especially when the equipment was sensitive or large in volume. Figure 12 summarizes the mean, minimum, and maximum times for the crew translation and equipment time. Comments indicate that the design of the tunnel entrance and the placement of handholds were acceptable (table 10); however, a few more handholds could be added to the tunnel for easier translation.

In general, STS-57 crewmembers pushed off hard once and then used lighter pushes and hand dragging to transfer through the tunnel. It was stated that they used handholds as mobility aids the majority of the time. They did not use their feet during the tunnel translation. It was observed that both hands were used to move their body, with arms stretched out to their sides when no equipment was transferred. However, hand push-offs were done beneath the body when carrying objects.

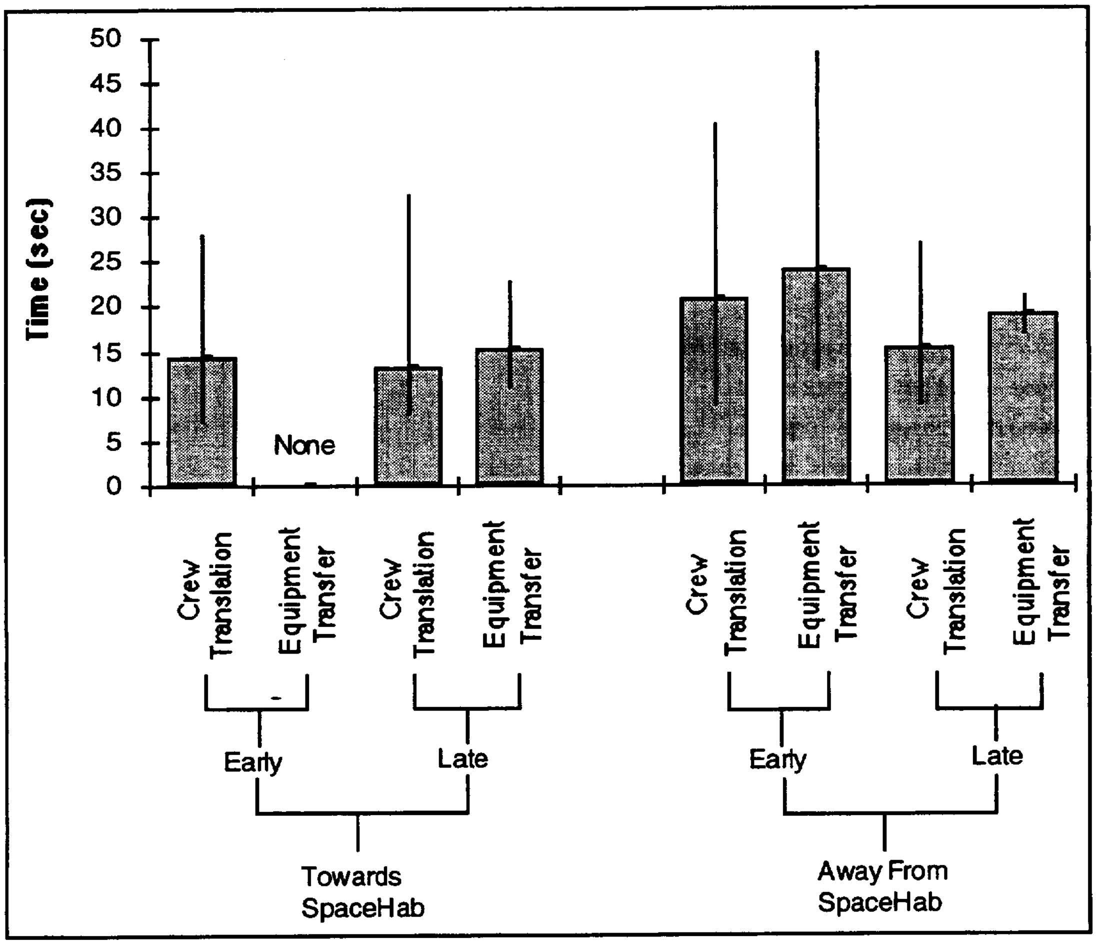

Figure 12. Summary of translation times.

Table 10. Summary of Crew Questionnaire Responses

Question	Number of Responses		
	Unacceptable/ Strongly Disagree	Borderline/ Unsure	Acceptable/ Strongly Agree
1. Tunnel entrances design:	1		5
2. Tunnel handholds - crew translation:			6
3. Tunnel handholds - equipment transfer:			5
4. Hatch handholds for navigation out of SpaceHab:		1	5
5. Hatch handholds for navigation into SpaceHab:		1	5
6. Translation took longer w/ equipment:		1	5
7. Translation time varied per direction:	5	1	
8. Translation time varied per equipment size:		1	5
9. Translation varied per equipment size:			6
10. Translation time changed w/ practice:	1	1	4
11. Translation technique changed w/ practice:	2	1	3
12. Comment on any important aspects:	—	—	—

CONCLUSION

Early in the mission, translation towards the middeck took slightly longer; however, no difference was evident by the end of the mission. The time required to translate through the SpaceHab tunnel was slightly longer when a crewmember was carrying equipment, particularly if the object was sensitive or large in volume. Crewmembers grasped the handholds on either side of their bodies to pull themselves through the tunnel when no equipment was being carried. However, when carrying objects they used hand push-offs beneath their body. The tunnel entrance design and the placement of handholds were considered acceptable by the crew. It was indicated that the addition of more handholds would make translation through the tunnel easier. The information collected on STS-57 along with that already collected during STS-40 and STS-47 will be incorporated into a database of space and life sciences research and used in the development of human factors space standards. Additionally, it will be used to update the Man-Systems Integration Standards and to suggest improvements in Orbiter hardware design, training requirements/procedure definition, and timeline development.

VII. GENERAL CONCLUSION

Results from the HFA-EPROC study suggest that task completion times are faster for computer procedures than for written procedures. The crew indicated that a primary advantage of computer procedures over paper procedures is that the current procedural step can be highlighted automatically. In addition, when using paper procedures extra time is required to clip or tether procedures in the vicinity of the work area and to ensure that the writing utensils are not free floating. It is recommended that future versions of electronic procedures continue to offer the capability of moving from one step to the next using either the keyboard or trackball. The addition of keyboard redundancy allowed the crew to move on to the next step in the procedures while keeping the cursor in the working portion of the display (the task display). These findings and findings from similar studies will enable designers to create more powerful, usable electronic procedures systems. This is especially critical since future, longer duration missions will rely

increasingly on electronic procedures because they are more easily launched, can be updated in flight, and offer automatic or on-request capabilities that are not available with paper.
Light levels across all measured work surfaces in the middeck, flight deck, and SpaceHab met the required brightness ratio and were rated as nominal, completely acceptable, or reasonably acceptable by the crew. With the auxiliary lighting on, SpaceHab was stated as being "much better illumination-wise than the middeck" by one of the crewmembers. In reference to problematic areas of illumination, crewmembers commented and agreed that sun shafting through the aft and overhead windows washed out the normal illumination and caused glare on areas such as the flight deck television monitors and electronic displays. In addition, some areas along the SpaceHab outer walls were stated as being noticeably dimmer than the general or central area.

Based on findings from the HFA-Quest and other evaluations, it is clear that questionnaires do provide a means of obtaining useful data for the evaluation of crew interface and design issues. However, as would be expected, the utility of the data collected is highly dependent upon the ability to gain access to the user of the system (in this case the SpaceHab crew). While the implementation of a questionnaire through electronic means proved to be a viable alternative, its use must be carefully examined since its operation requires additional timeline, power, and working volume requirements. Furthermore, the use of a computer in the current study did not appear to elicit more comments than the written version. During the current study, the combination of an overburdened timeline and ongoing experiments left one crewmember with no place to attach the computer and foot restraints, resulting in loss of data. Similar scheduling and timeline difficulties were responsible for only two crewmembers completing the HFA-Quest electronically.

Results of the noise study indicated that while mission operations were not significantly impacted by noise, the crew found it necessary to use earplugs during sleep and the ICOM while on the same deck. Crewmembers also experienced interference in their ability to concentrate, relax, sleep, and communicate verbally. And some reported fatigue and headaches due to the noise levels. The flight deck was considered the most acceptable of all three habitable volumes and returned a sound pressure level of 63 dBA. During nominal operations, half of the crew found the middeck noise level to be acceptable. Ratings were a little harsher during experiment operations. The equipment noted as noise sources included the TAGS, the ergometer and the galley pumps. Two crewmembers rated noise levels in SpaceHab as unacceptable during minimum background noise conditions. The EFE and the SpaceHab fans were identified as among the major noise sources. One individual recommended that CMAM continue to request that the fan clamps be loosened once in orbit because the procedure made a marked improvement in the SpaceHab acoustic environment. Crew comments indicate that the equipment most in need of acoustic reduction efforts are the vacuum cleaner and EFE. Noise reduction efforts were also recommended for the ASPEC and the TAGS.

Translation towards the middeck took slightly longer early in the mission; however no such difference was evident by the end of the mission, suggesting a practice effect took place. The time required to negotiate the SpaceHab tunnel was slightly greater when crewmembers were carrying equipment than when they were not, especially if the object was sensitive or large in volume. Translation techniques differed based on whether equipment was being transferred or not. Crewmembers grasped the handholds on either side of their bodies to pull themselves through the tunnel when no equipment was being carried. However, when carrying objects they used hand push-offs beneath their body. Design of the tunnel entrance and the placement of handholds were considered acceptable, although the crew indicated that the addition of more handholds would make translation through the tunnel easier. Crewmembers also reported occassionally bumping their head or back when entering the SpaceHab module.

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13. ABSTRACT *(Maximum 200 words)*

SpaceHab-1 (STS-57) was the first of six scheduled Commercial Middeck Augmentation Module (CMAM) missions seeking to offer entrepreneurial companies an opportunity to use the resource of microgravity. The SpaceHab module, which occupies about one-fourth of the payload bay, is approximately 2-3/4 meters (9 feet) long and 4 meters (13.5 feet) in diameter. It provides a shirt-sleeve working environment and contains the storage space equivalent of 50 Middeck lockers--considerably over and above the number of experiments that can be carried in the Orbiter middeck alone. A modified Spacelab tunnel links the SpaceHab module to the middeck. While in orbit, the Orbiter payload bay doors remain open, exposing the padded exterior of the lab and tunnel to space until preparation for reentry at the end of the flight. The crew for SpaceHab-1 was comprised of four males and two females, each of whom participated in some part of the human factors assessment (HFA) evaluation.

The HFA was one of over twenty experiments manifested on this maiden flight of the SpaceHab module. HFA consisted of HFA-EPROC, HFA-LIGHT, HFA-SOUND, HFA-QUEST, and HFA-TRANS. The goal of HFA-EPROC was to assess the advantages and disadvantages of paper versus computer presentation for procedural tasks. The second of two evaluations investigated the modules' lighting and acoustic environment. HFA-TRANS sought to evaluate the design of the SpaceHab tunnel and to characterize translation through it. HFA-QUEST represented a consolidation of the in-flight questions generated by the HFA principal investigators involved in the acoustic, lighting and translation studies.

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