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STS-41 Voice Command System Flight Experiment Report

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STS-41 Voice Command System Flight Experiment
Executive Summary

This report presents the results of the Voice Command System (VCS) flight experiment on the five day STS-41 mission. Overall, the experiment was a success. The two astronauts, mission specialists Bill Shepherd and Bruce Melnick, believe the system is a useful tool for the Shuttle. Their recommendation is to fly the VCS again on a longer flight to obtain more data on the performance of the VCS to user adaptation in microgravity. In addition, they recommend adding intelligent system commands such as macro commands to mimic several switch closures in performing Closed Circuit Television (CCTV) operations.

The astronauts used the VCS to control the CCTV system by voice. The experiment collected baseline data on the effects microgravity has on voice recognition. In addition, the experiment gave an initial assessment of the operational effectiveness of controlling a spacecraft system by voice.

Recognition scores on-orbit for Shepherd and Melnick were lower than ground training. During ground training Shepherd had an average training score of 95% with the flight templates. His on-orbit average score with the same templates was 62%. Melnick had an average training score of 98% and an on-orbit average score of 82%. Certainly, the actual environment played an important part of this outcome since this environment could not be simulated 100 percent on the ground when acquisition of the flight templates occurred. Shepherd and Melnick were highly successfuly in creating on-orbit voice prints of the command words and using them on flight day 4, scoring 94.7% and 100%, respectively.

Based on the recognition data recorded in the VCS, when Shepherd had poor recognition, several "Too Soft" messages were recorded, indicating lack of input volume. When he had relatively good recognition, several "TOO LOUD" messages were recorded. Apparently, microphone sensitivity was a contributor to his recognition difficulty. The VCS does not have automatic gain control and therefore could not compensate for microphone placement sensitivity.

The results of the experiment have proven valuable in acquiring data on the use of voice recognition technology in space. Consequently, improvements to the user feedback, more consistent training, investigation of using automatic gain control to reduce microphone sensitivity, better fine-tuning camera control methods, and learning CCTV scenes to create macros will greatly improve the VCS. The astronauts believe that the macro commands will make the VCS attractive for use during CCTV mission operations.

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ACRONYMS

CCTV	CLOSED CIRCUIT TELEVISION
EEPROM	ELECTRICALLY ERASABLE PROGRAMMABLE READ ONLY MEMORY
EPROM	ERASABLE PROGRAMMABLE READ ONLY MEMORY
HIU	HEADSET INTERFACE UNIT
JPL	JET PROPULSION LABORATORY
JSC	JOHNSON SPACE CENTER
MDF	MANIPULATOR DEVELOPMENT FACILITY
RMS	REMOTE MANIPULATOR SYSTEM
VCS	VOICE COMMAND SYSTEM
VLHS	VERY LIGHTWEIGHT HEADSET
VRU	VOICE RECOGNITION UNIT
VTR	VIDEO TAPE RECORDER

ACKNOWLEDGEMENTS

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1.0 Introduction

Future space programs, such as the Space Station or Lunar/Mars exploration, will require the crew to operate several spacecraft computer systems on a daily basis. Hundreds of manual switches associated with these systems will literally cover the walls and panels of the vehicle. This tactile form of control will require the crew person to remain near the control panel when using the system. Furthermore, the crewperson must remember the function of each switch and the proper sequence of switch closures to perform a specific task.

For multi-task operations such as robot arm control, the astronaut must operate the spacecraft's Closed Circuit Television (CCTV) system while simultaneously controlling the arm. The crewperson must stop the movement of the arm each time an adjustment or selection of a camera or monitor is made. This disrupts the robot motion, diverts the astronaut's visual attention, and distracts his mental concentration.

On Shuttle there exists this kind of operational situation. The Remote Manipulator System (RMS) requires the use of the Shuttle's CCTV system. This system requires the astronaut to learn approximately 30 switches for controlling the selection of monitors, cameras, or camera-actions (e.g., pan, tilt, zoom).

In 1981 a pilot voice control system test developed at the Jet Propulsion Laboratory (JPL) investigated the potential use of voice control on Shuttle as a possible enhancement of Shuttle operations. They chose to incorporate voice control into the Shuttle's CCTV system because of the simultaneous operation required with the manipulator and the number of CCTV switches required to operate the system.

Installation of the prototype system occurred in the Manipulator Development Facility (MDF) at the Johnson Space Center (JSC). The MDF is a full-scale mock-up of the Shuttle AFT-Flight Deck and cargo bay including the RMS and CCTV systems. Test subjects controlled the CCTV system by voice while using the full-scale Shuttle manipulator to berth, maneuver, and deploy a simulated science payload. The investigators at JPL and JSC concluded that the use of voice control contributes to a better man-machine interface, and that a flight voice command system for the Space Shuttle should be developed. To investigate the potential use of this technology in an actual spacecraft, a flight experiment called the Voice Command System (VCS) was developed at JSC and flown on STS-41.

This report presents the results of the experiment. The VCS allowed two astronauts to operate select CCTV functions by issuing commands such as "camera alpha," "monitor one," or "zoom-in." The VCS recognized the spoken commands and operated the appropriate controls of the CCTV system. The experiment consisted of the VCS control panel located directly below the CCTV switch panel, a display unit for VCS status feedback, and interconnecting cables between it and the Orbiter.

Unlike the JPL test, the VCS flight experiment did not consist of using the system with RMS operation. Rather, the purpose of the experiment was to observe the effects microgravity has on voice recognition and to assess the operational effectiveness of voice controlling a spacecraft system in an actual space environment/mission operation. In addition, the experiment provided data on exploring the concept of using speech recognition as a viable tool for spacecraft control rather than attempting to test the specific recognition hardware/software which are dependent on current technological limitations.

This report does not make conclusions about the recognition accuracy of the experiment since statistically the data/test subjects are insufficient. However, the report does discuss possible improvements to the VCS as well as future space voice control units based on the outcome of this experiment.

This report is intended for a broad audience. There is sufficient detail to familiarize a person with the VCS flight experiment. For the person already familiar with the VCS flight experiment, the experiment results section and conclusion can be read first.

2.0 Flight Experiment Description

2.1 Overview

The VCS is a speaker-dependent voice recognition device designed to control the Orbiter's CCTV system by voice. The VCS allows an astronaut to operate selected CCTV functions (except camera power switching). Key elements of the unit consist of a display unit to provide system status, a control panel, a command and control computer, the voice recognizer, and the interconnecting cables from the VCS to the Orbiter. Figure 1 shows the block diagram of the VCS interfaces with the Orbiter. Figure 2 shows the location of the VCS in the Orbiter.

To ensure that the VCS did not impact the CCTV system, the VCS interface to the CCTV system was opto-isolated. This allows the CCTV switch panel to work in parallel with the VCS on or off. Operation of the VCS requires the crewmembers to use a standard Very Lightweight Headset (VLHS) and a Headset Interface Unit (HIU) configurable for hot-mic, push-to-talk, or push-to-disable via the VCS front panel.

At the heart of the VCS is a voice recognition unit (VRU) manufactured by Spacecraft Incorporated, of Huntsville, Alabama. The VRU is speaker-dependent requiring the user to create a set of personalized voice prints or templates for the command words. Table A-1 shows the command words used for the experiment. The unit also provides syntaxing, recording of messages, and playback of recorded messages.

MONITOR 1 (TV 1)	FOCUS FAR
MONITOR 2 (TV 2)	OPEN IRIS
ALPHA	CLOSE IRIS
BRAVO	PEAK
CHARLIE	AVERAGE
DELTA	NORMAL
VTR	STOP
MIDDECK	CHANGE RATE
FLIGHTDECK	MORE
GO (ACTION)	TOO MUCH
STANDBY	EASY
ACTIVATE	STOW CAMERAS
UP (TILT UP)	STOP(TO STOP"STOW CAMERAS" CMD)
DOWN (TILT DOWN)	VOICE COMMAND
ZOOM IN	ACTIVATE
ZOOM OUT	SHEP
LEFT	MEL
RIGHT	ACTIVATE*
FOCUS	

Words in parenthesis are Melnick's chosen command words

TABLE A-1 VOICE COMMAND SYSTEM VOCABULARY

* The activate command word is used for transitioning from the action node to the monitor/camera node. The other activate command word is annunciated after "voice command" to go from the standby to the monitor/camera node.

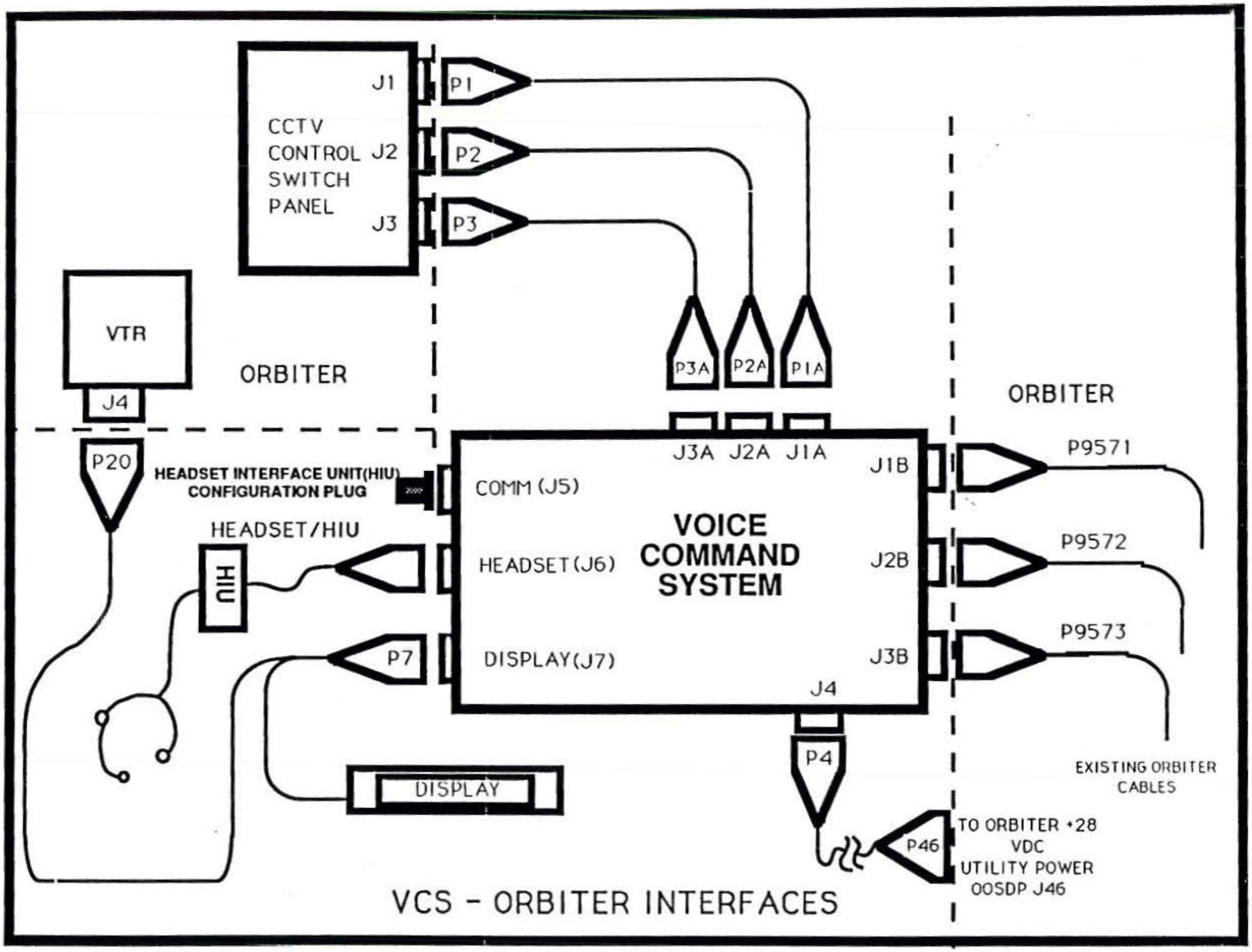


FIGURE 1. VOICE COMMAND SYSTEM INTERFACES WITH THE ORBITER

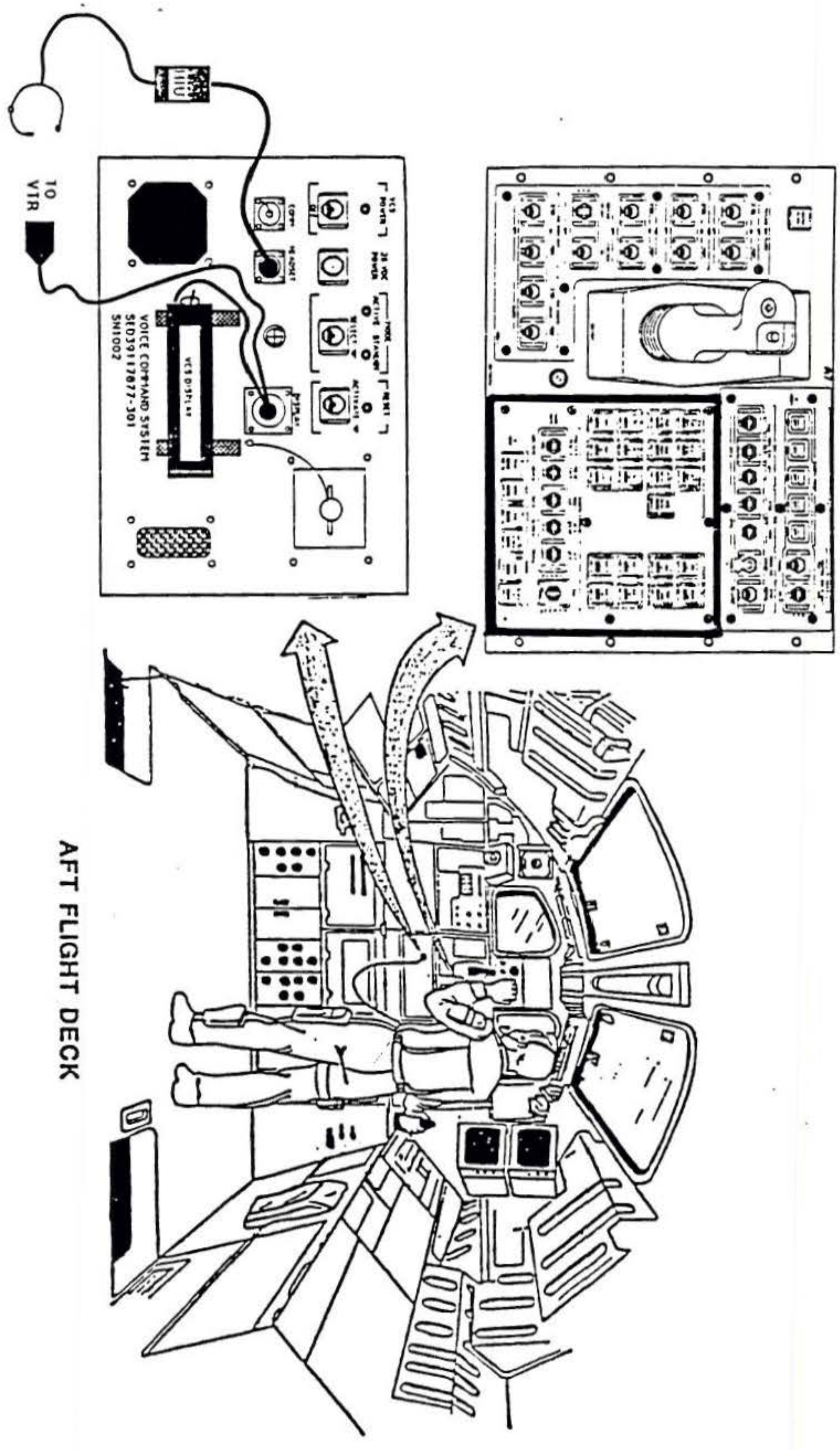


FIGURE 2. VOICE COMMAND SYSTEM LOCATION IN THE ORBITER

2.2 System Features and Controls

The STS-41 flight configuration of the VCS allowed voice control of the Shuttle's four payload bay cameras mounted on pan/tilt units. In addition, the flight deck and mid-deck cameras located in the crew cabin were also under VCS control. Selecting a monitor and recording onto the Video Tape Recorder (VTR) from any camera was selectable by voice as well. The VCS controlled camera-actions such as pan left/right, zoom-in/out, tilt up/down, focus, and iris functions. Figure 3 shows the flight experiment system configuration. Figure 4 and 5 are photographs of the actual flight hardware.

The VCS provides for multi-action camera commanding. For example, the astronaut could command a payload bay camera to pan left, tilt up, and zoom-out simultaneously. Repeating the last command word stops the first two actions and continues with the last one. Three unique commands allow for fine-tuning of camera-action commands. The three commands, "more," "too much," and "easy" compensate for latency time in processing the "stop" command. The "more" command bumps the last active command by two degrees in the forward direction. "Too much" bumps the last active command in the reverse direction by two degrees. "Easy" bumps the last active motion command by a fraction of a degree. One macro command was incorporated into the flight software. The "stow cameras" command word would cause all four payload bay cameras to stow into their approximate ascent and reentry configuration. However, due to lack of time, this macro was not fully exercised.

Operating the VCS requires only three switches: power, reset, and mode. The power switch provides power from the Orbiter to the VCS. The reset switch restarts the system if an error occurs with the software. The switch also serves to clear the user's templates from the active memory of the voice recognizer when a new user is ready to use the system.

The mode switch allows the user to place the VCS into the active mode (listening for CCTV commands) or standby mode (non-listening for CCTV commands) by toggling the momentary switch once. This control is not mandatory since the modes are voice selectable. In addition, this switch doubles as the template retrain mode switch. By toggling the switch twice within two seconds, the system enters the template retrain mode where the user can create new voice prints of all the command words. An audio and display message appears to the user on the headset and VCS display, respectively. Afterwards, the command word list appears on the VCS display, one word at a time. The VCS requires the user to speak each word (except the log-in words) twice until all words have been trained. Upon completion of retraining all command words, the system goes directly to node 1 (see Fig. 6). However, the templates created are volatile and therefore lost when the system is powered-down.

2.3 SYSTEM COMMANDING

The commands that operate the VCS closely parallel the switch control functions on the CCTV switch panel. A vocabulary of 41 command words corresponds to 23 of the 33 CCTV switch-panel-related commands, 12 VCS unique commands, and 6 user login names.

These commands are grouped into nodes. This results in an increase in both speed and accuracy of the recognition since the recognizer searches through a limited number of templates at one time. Figure 6 shows the node structure. Transition words are used to move the user from one node to another. When a transition word is recognized, the current set of node templates become inactive and a new set of templates, associated with the spoken transition word, becomes active.

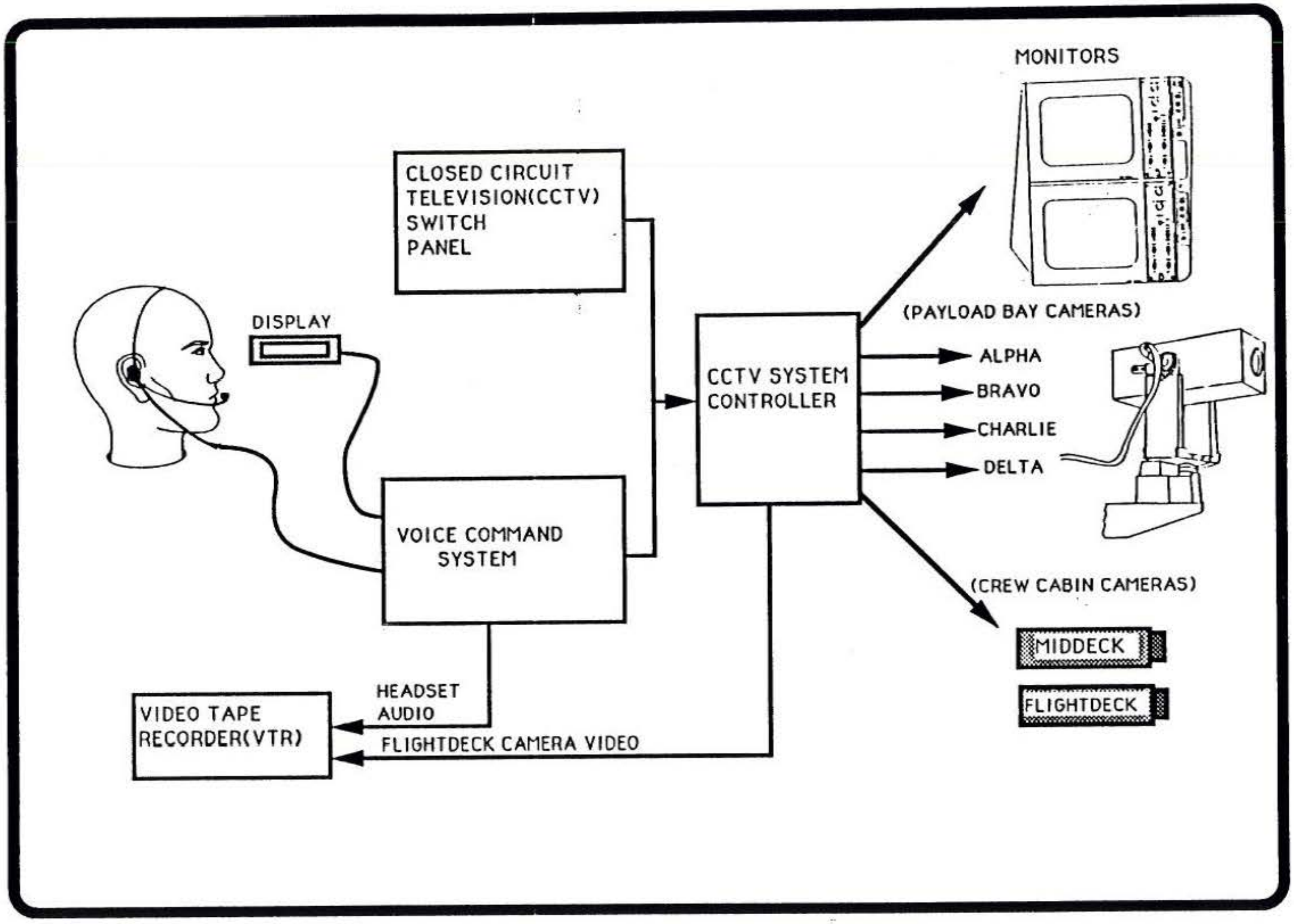


FIGURE 3. FLIGHT EXPERIMENT SYSTEM CONFIGURATION

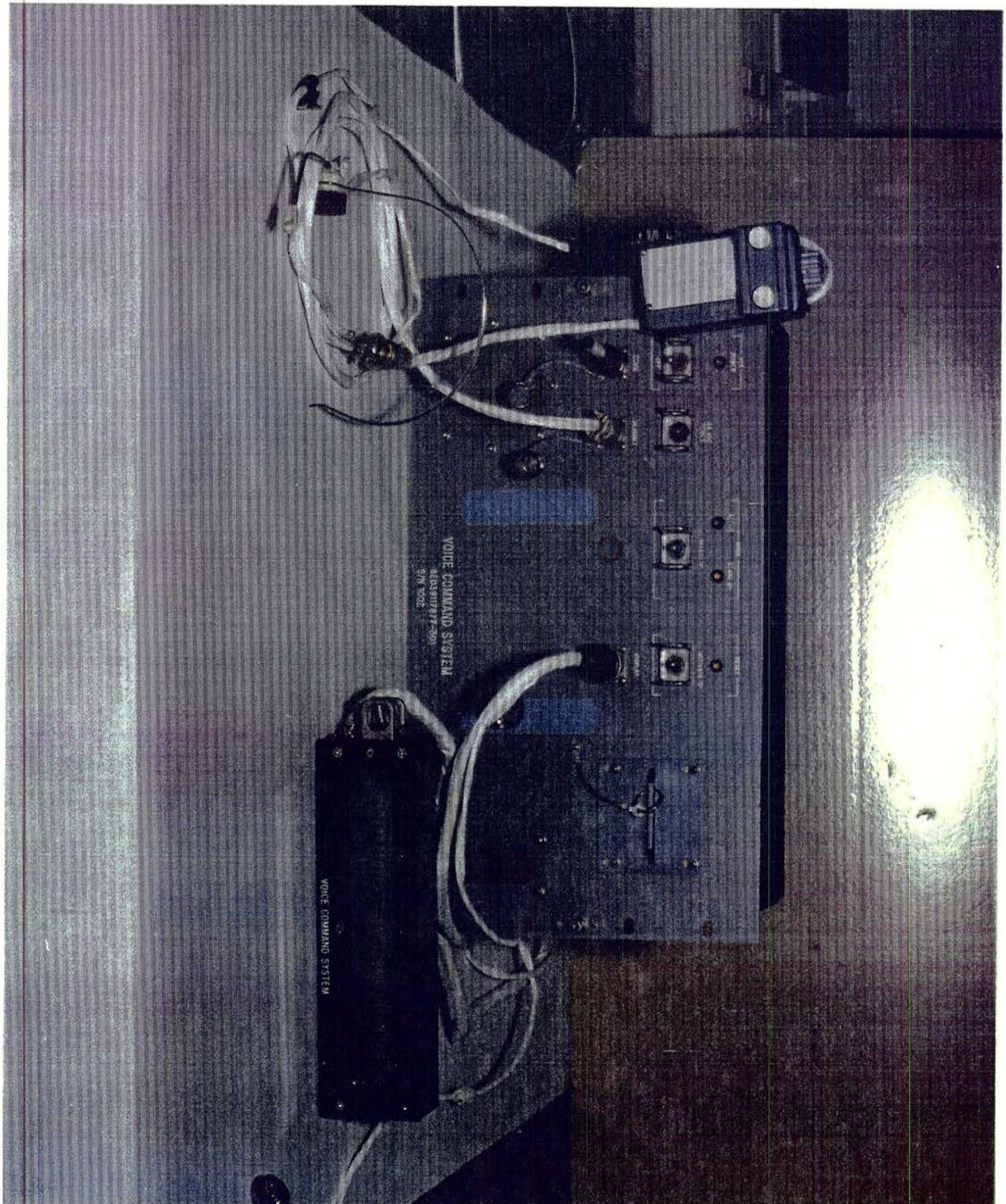


Figure 4. Voice Command System Flight Hardware

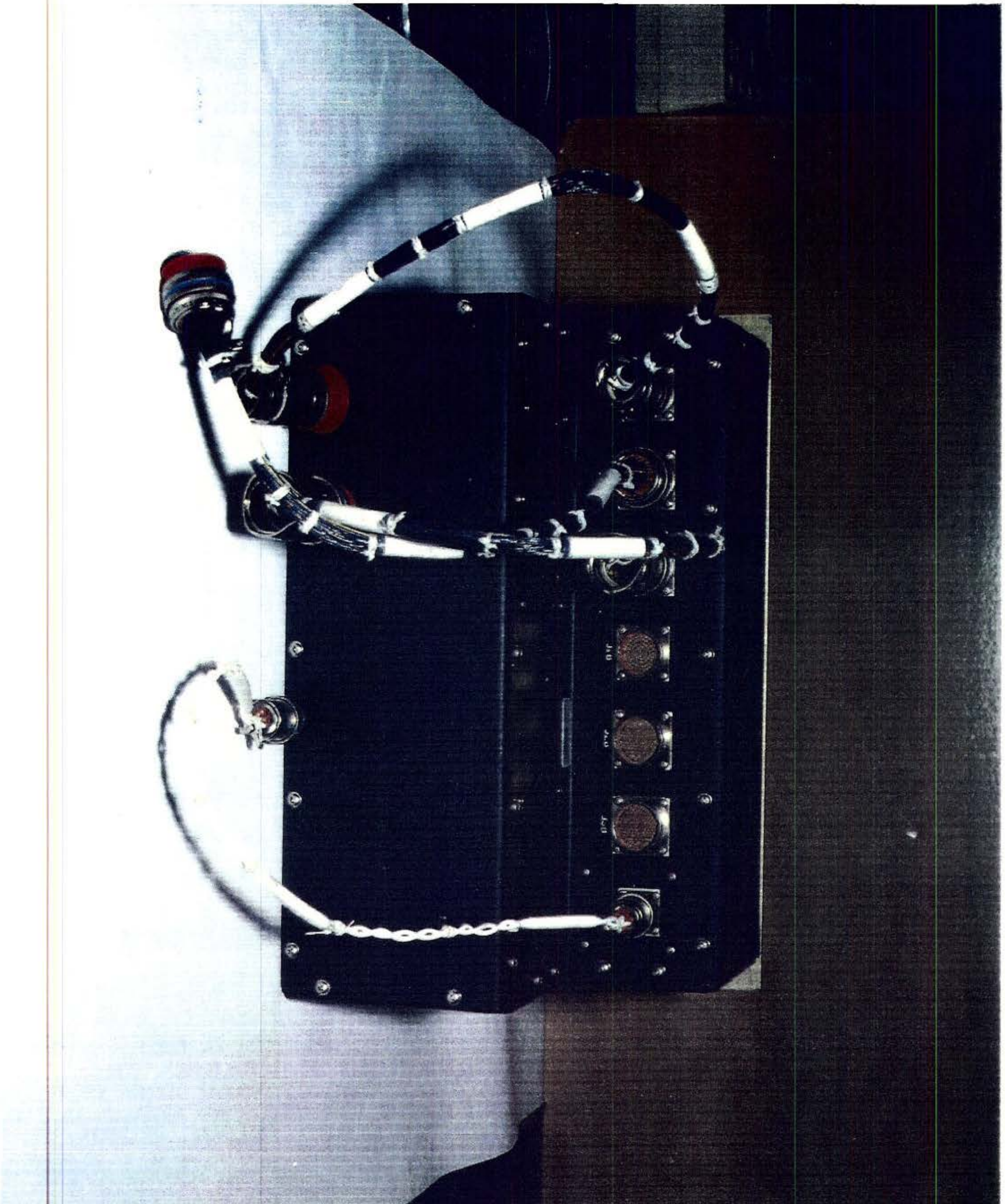


Figure 5. Back View of Voice Command System

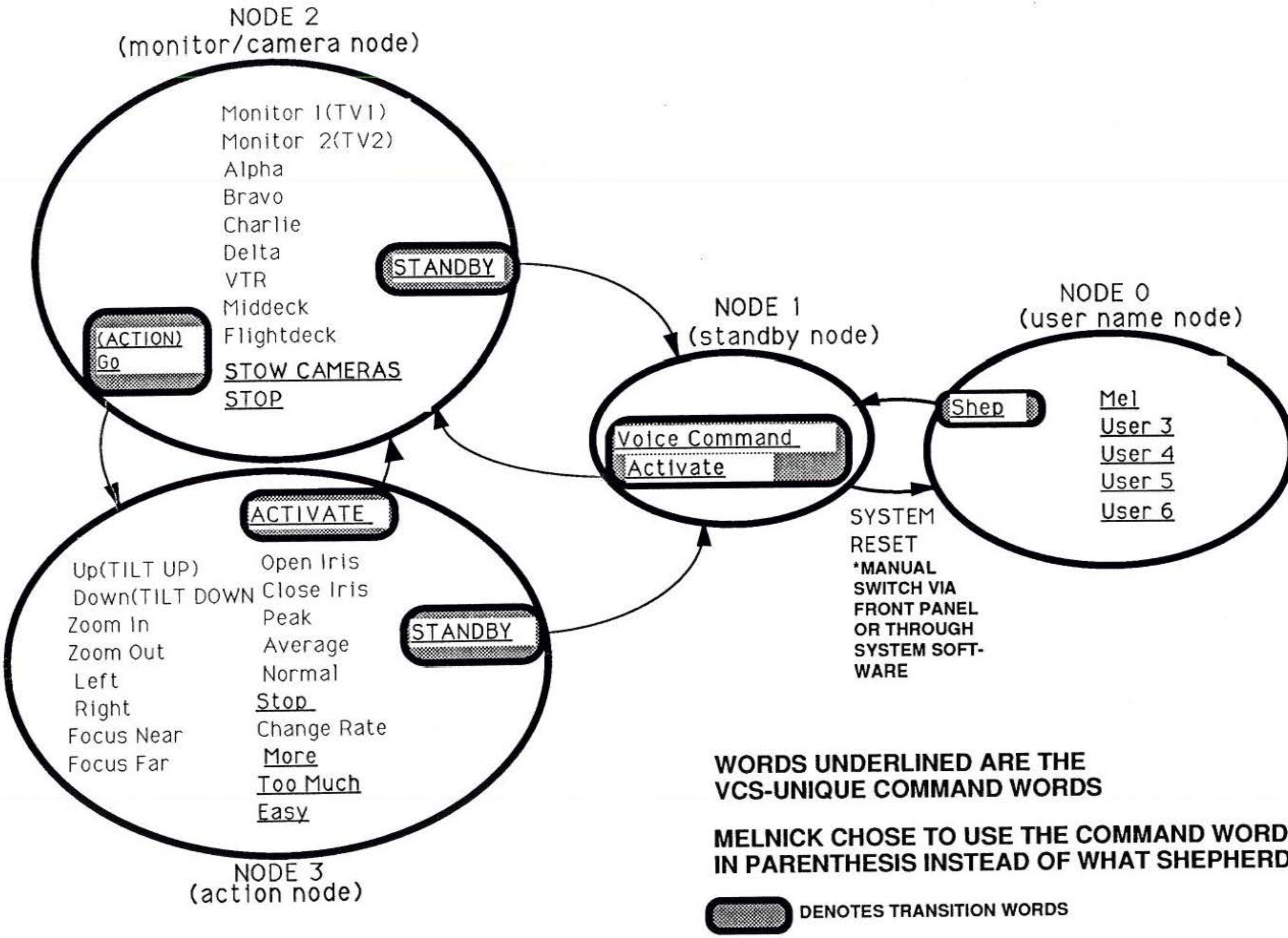


FIGURE 6. NODE STRUCTURE FOR SHEPHERD

Upon power-up or reset, the system enters the user name node (node 0). The system then prompts the user to state their name. Once the VCS has recognized the user, the system transfers the user's personalized template file into the VRU's memory. Afterwards, the system moves the user into the standby node (node 1).

This node relaxes the system so astronauts can converse without inadvertently activating CCTV system functions. Only the node transition command sequence "voice command" followed by "activate" within three seconds will move the user into the camera/monitor node (node 2).

Node 2 allows the user to select a monitor and then a camera. Afterwards, the user proceeds into the action node (node 3) by saying the node transition word "go" or "action." Once in this node the user can select camera-action commands such as pan, tilt, and zoom. The command word "activate" moves the user back to node 2. "Standby" moves the user back into the standby node. During system commanding the VCS display provides feedback to the user. Monitor, camera, and camera-action selection are displayed as shown in figure 7.

3.0 TRAINING

3.1 Initial Training

The initial training for each astronaut on the VCS consisted of approximately twelve hours over a five week period. The VCS Familiarization Class occurred on April 11, 1990. It provided an overview of the VCS for the entire STS-41 Shuttle crew members, flight controllers, training personnel and other interested parties. This session also provided astronauts Bill Shepherd and Bruce Melnick their first opportunity to use the VCS.

Next, four one hour sessions were conducted with the familiarization trainer. The familiarization trainer familiarized Shepherd and Melnick, with the process of voice recognition and with controlling the CCTV system in the MDF by voice. This trainer functioned similar to the flight unit with the exception that template storage resides in a 3-1/2 inch floppy diskette instead of Erasable Programmable Read Only Memory computer chips, (EPROM).
The final six hours of training occurred with the back-up flight unit in the VCS laboratory, a reverberation chamber and the MDF.

Throughout the training session the primary objectives were for the crew members to become familiar with the technology and operation of the VCS and to extract a good set of templates for the flight. The vocabulary words selected for commanding the CCTV system reflect the nomenclature of the existing CCTV switch panel functions. Both astronauts modified certain command words according to their personal preferences. The modified words also increased their recognition accuracy. A goal was targeted to obtain a set of templates with all the first choice scores less than 20, all the second choice scores greater than 40 and a first choice recognition score acceptance level limit of 30 (using a scale between 0 and 255 where 0 is a perfect march).

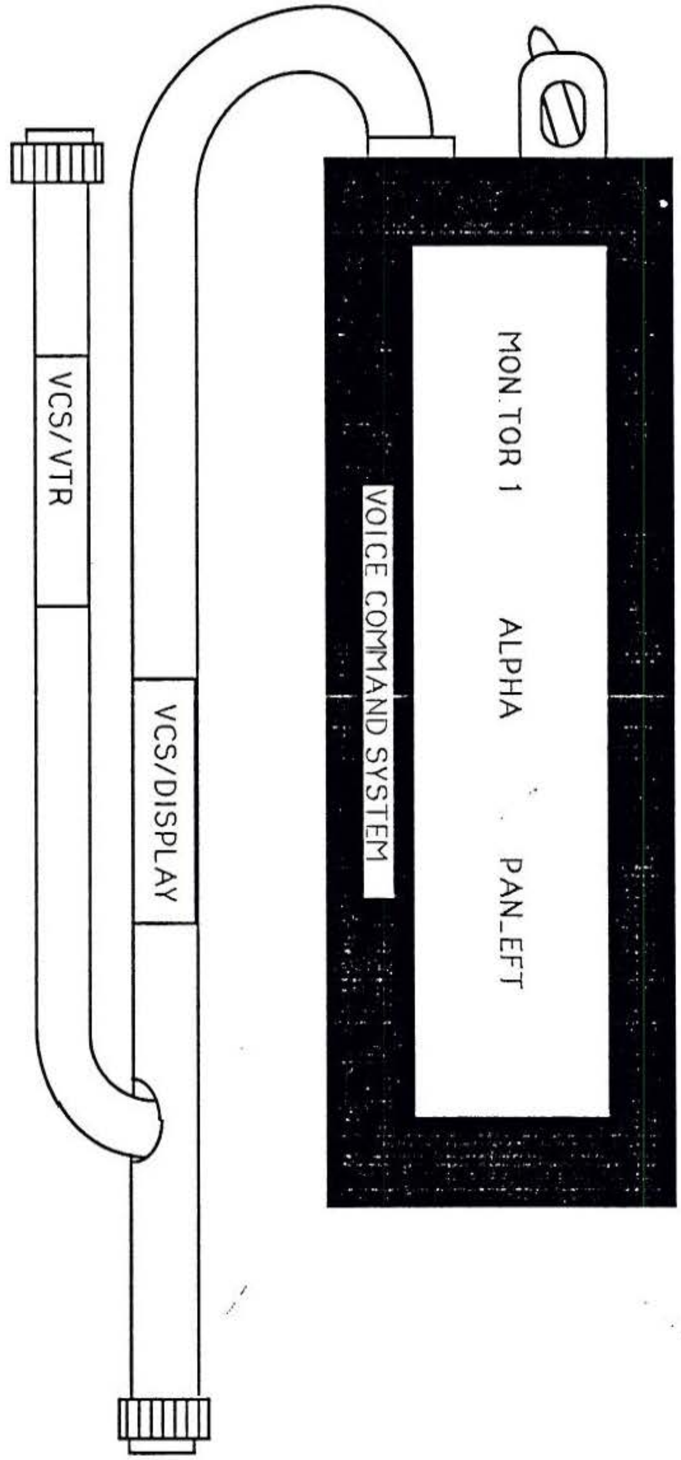


FIGURE 7. VOICE COMMAND SYSTEM DISPLAY FEEDBACK

3.2 Extracting Flight Templates

Testing occurred in a reverberation chamber with simulated, on-orbit noise and in the MDF to determine which environment would be best for obtaining the final flight templates. Both the reverberation chamber and the MDF produced templates with acceptable recognition scores well within our target goal. The final decision was to use the MDF to obtain and then verify the final flight templates since this provided as realistic an operational environment as possible, except for the background noise and uplink audio messages.

On May 8, 1990, the final flight templates for Bill Shepherd were acquired and then verified a week later. The final flight template acquisition for Bruce Melnick occurred on May 15, 1990 and verified on May 18, 1990. Figure 8 shows the ground training results using the final flight templates for Shepherd and Melnick. Shepherd had an average first score of 16 and an average delta (difference between the first and second choice scores) of 23. Melnick had an average first score of 16 and an average delta of 31. Hence, the target goal for recognition accuracy was met.

The following definitions apply for Figure 8 and the remainder of this report:

- o Recognition accuracy or accuracy rate was the percentage of spoken command words that were correctly identified and processed.
- o Omission or false rejection errors were legal command words spoken that were not identified or processed.
- o Substitition errors were legal command words spoken that were incorrectly identified as an another word in the vocabulary and processed.
- o Insertion errors were illegal words spoken (not in the vocabulary) that were incorrectly identified and processed as legal command words.

The final flight templates were then assembled into the VCS flight unit which was tested, certified for flight, and then sent to the Kennedy Space Center (KSC) for installation in the Shuttle Discovery. The backup flight unit also had the flight templates installed into it for training.

3.3 Final Training

On August 15, 1990 Shepherd and Melnick each had a one-hour training session in the MDF using the backup flight unit. On August 22, 1990 Shepherd used the VCS during a scheduled Remote Manipulator System (RMS) training session. At the completion of the session Shepherd commented that using the VCS in conjunction with the RMS was a little confusing at times but that if he worked with the VCS more it would probably be as easy as using the manual switches. Figure 8 incorporates the session results. Due to time constraints for the crew members, no additional training time was available until their quarantine period. This final training session occurred on October 2, 1990 in which both Shepherd and Melnick used the system for one hour. During this session Melnick had problems with three command words: "normal," "zoom in," and "zoom-out."

VCS RESULTS FOR SHEPHERD & MELNICK
AVERAGE DURING TRAINING WITH FLIGHT TEMPLATES

Figure 8

4.0 ON-ORBIT EXPERIMENT DATA COLLECTION

Acquisition of recognition, video, and audio data occurred in each flight experiment session. The recognition data consisted of the first and second choice words and their associated confidence scores. Recognition of a spoken command word would cause the recognizer to generate this data. The VCS stored this data in novolatile memory after the VCS identified the first choice word and determined the appropriate CCTV controls to initiate. The video and audio data recorded on the Orbiter's VTR showed the astronauts performing the experiment. The VTR recorded video from the Flight deck camera and the astronaut's audio from the VCS. The VTR tapes for the three sessions were used to correlated the recognition data recorded in the VCS memory.

5.0 EXPERIMENT RESULTS AND DISCUSSION

5.1 On-Orbit Results

The first VCS session during STS-41 occurred on October 7, 1990, flight day two. Shepherd reported very poor results with approximately 50 percent recognition and even less after using the retrain mode due to not being able to enter node 3. He also reported that Melnick had better results, but still had problems with a couple of words.

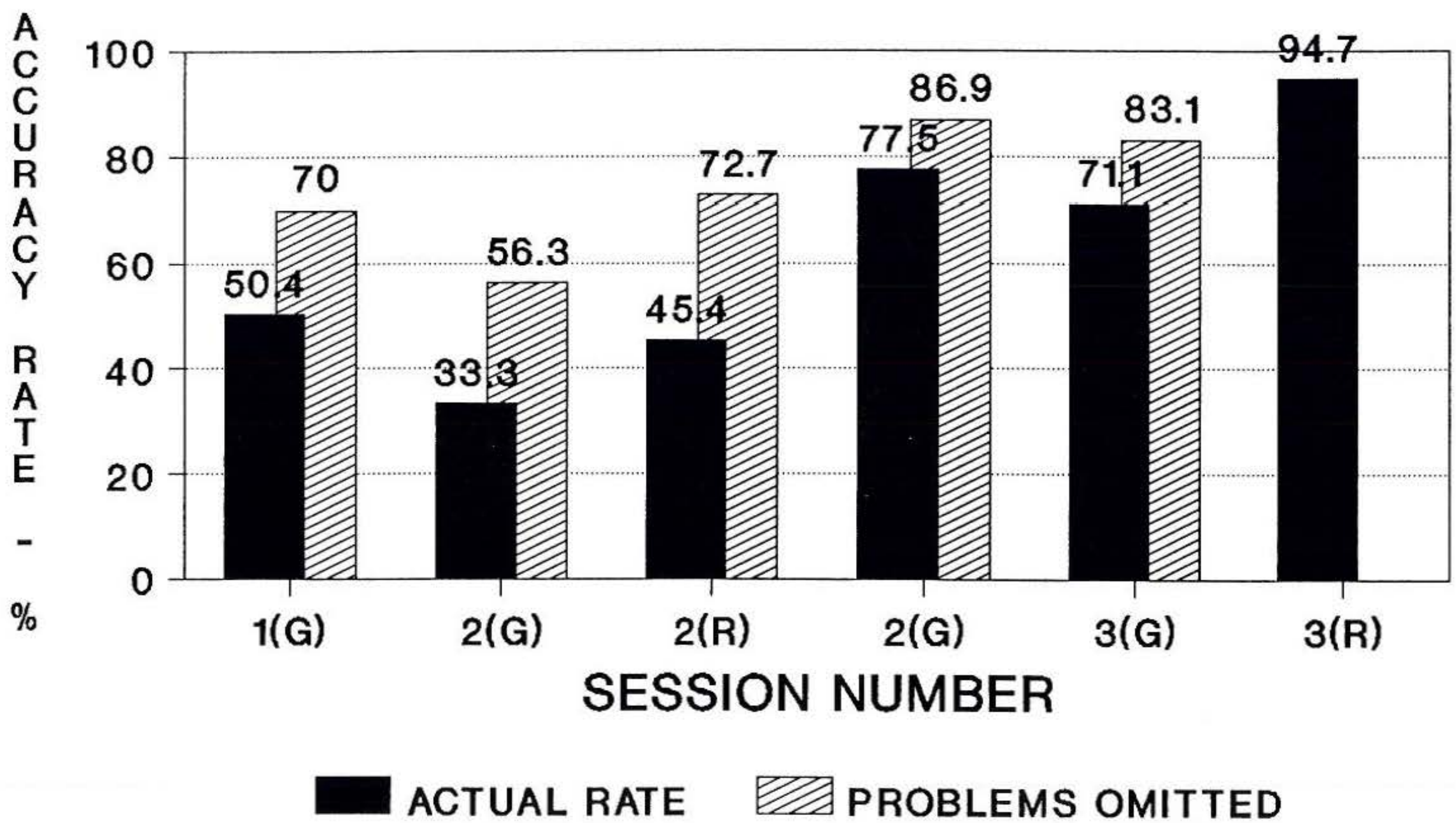
Figure 9 and 10 show the accuracy rate during all three sessions for Shepherd and Melnick, respectively. The solid bar graphs represent the actual recognition accuracy rate. As can be seen, the results were less than that experienced during training. During the experiment, each crew member had a small set of problem words consistent throughout all the sessions. A comand word was considered a problem word if it caused 5 or more errors in a session. Therefore, even though the accuracy rate was much lower than expected, in general, a small set of words caused most of the errors. Omitting these problem words increased the accuracy rate approximately 20 percent. The hatched bar graphs represent the accuracy rate with the problem words omitted. Interestingly, the astronauts comments regarding system performance appeared to reflect the higher accuracy rate with problem words omitted. For example, during this first session Melnick commented that the system recognized everything except zoom-in and zoom-out. Table A-2 shows the problem words for Shepherd and Melnick encountered during the STS-41 flight experiment.

The second VCS session occurred on October 8, 1990, flight day three. Live video was downlinked from the Shuttle for this session. Unfortunately, no audio was available with the downlinked video. Shepherd continued to have problems with his ground templates. Retraining new templates did not significantly improve his results, contrary to what was expected. The retrain should have created templates of his on-orbit voice. Shepherd adjusted his microphone numerous times during the retrain to get the VCS to accept new templates. Reviewing the video tapes recorded during this time showed that the VCS would not allow new templates to be created when the volume level was too low. In addition, the EEPROM data recorded several "TOO SOFT" messages while trying to use the retrained templates to control the CCTV system. At the end of this session Shepherd had good results using his ground templates, comparable to Melnick during session 1. In comparison the EEPROM data recorded several "TOO LOUD" messages while using the ground templates during that period. Melnick continued to have good success with his ground templates.

The third and final VCS session occurred on October 9, 1990, flight day four. Both Shepherd and Melnick continued to have good success with their ground templates. In addition, they both reported 100 percent recognition using retrained templates (Figure 11). Figure 12 shows the overall recognition score averages during the flight experiment.

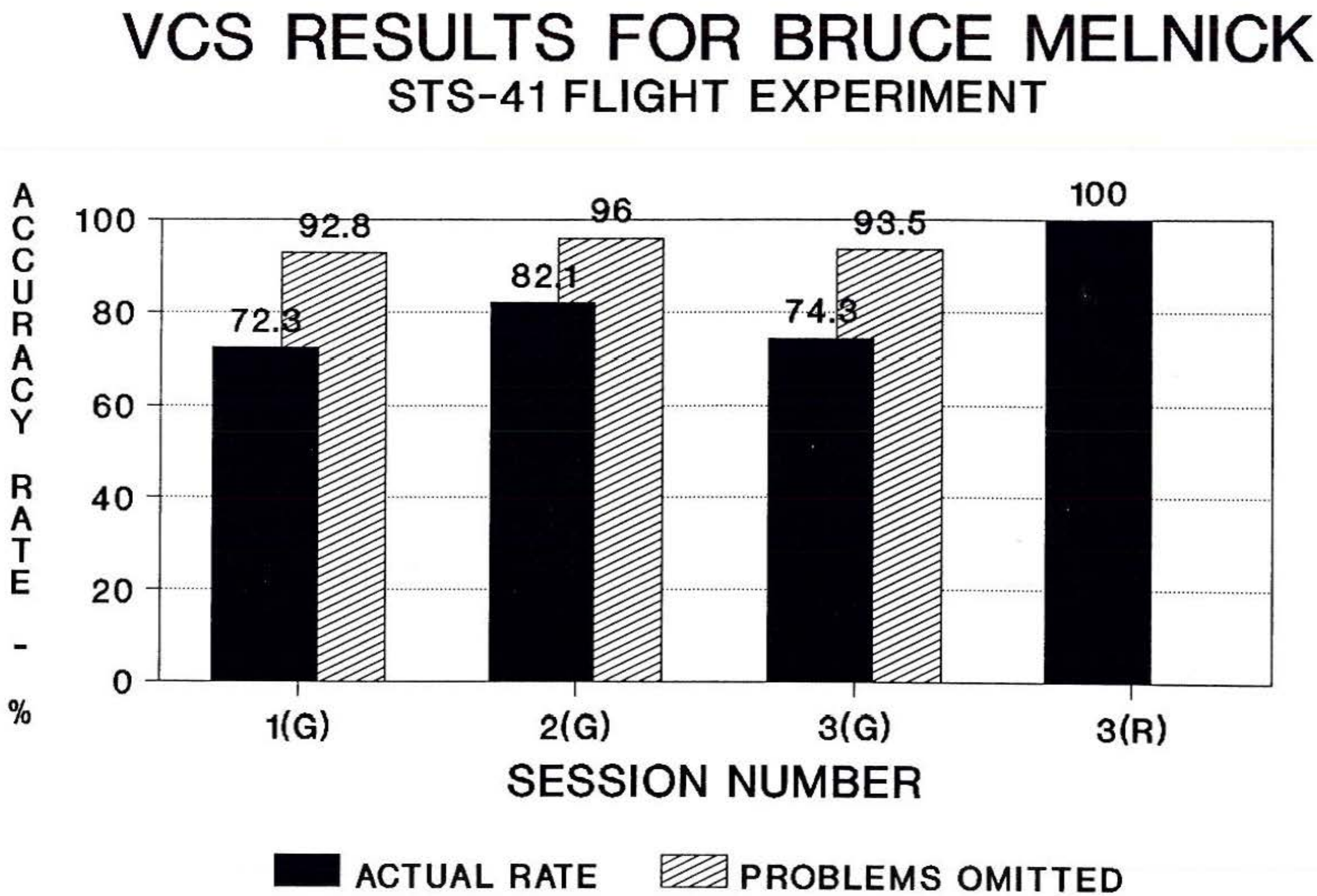
VCS RESULTS FOR BILL SHEPHERD

STS-41 FLIGHT EXPERIMENT



G = Ground, R = Retrain Templates

Figure 9



G = Ground, R = Retrain Templates

Figure 10

Figure 10

VCS RESULTS FOR SHEPHERD & MELNICK

FINAL RETRAIN TEMPLATES DURING STS-41 FLIGHT EXPERIMENT

Figure 11

VCS RESULTS FOR SHEPHERD & MELNICK
AVERAGE DURING STS-41 FLIGHT EXPERIMENT

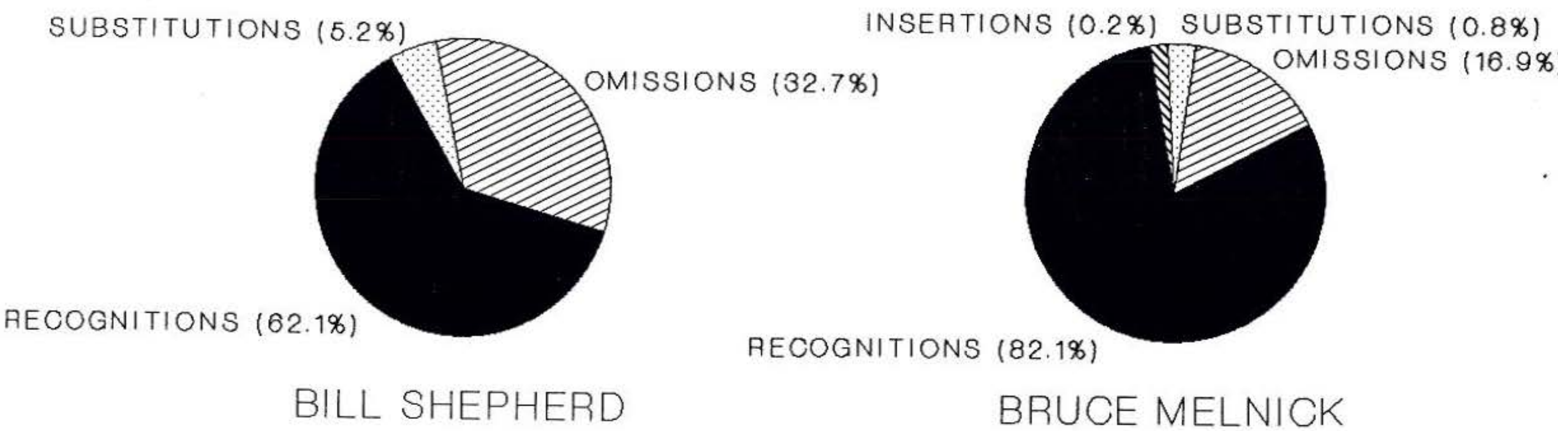


Figure 12

Shepherd	Melnick
Monitor 1	Stop
Monitor 2	Normal
Charlie	Zoom in
Delta	Zoom out
Open Iris	Alpha
zoom in	

Table A-2. Problem words for Bill Shepherd and Bruce Melnick.

5.2 Post-Flight Analysis

All the flight hardware functioned nominally except for two discrepancies. First, when sending a CHANGE RATE command to the CCTV Remote Control Unit (RCU) it would not respond until issuance of a subsequent command occurred. However, the RCU in the MDF would accept the change rate command without a subsequent command. Second, unique conditions during recognition caused a volume/gain error of certain camera-action words. The VCS voice recognition unit sent the recognize word but with an error message also. Consequently, the VCS controller would not send the control signal to the RCU but instead it would send the message to the display indicating that the command was recognized and accepted. While these two discrepancies did cause some confusion for the crew members, it did not have an adverse effect on the experiment. These problems will be addressed and resolved at a later date.

A post-flight training session was conducted on October 22, 1990 in the MDF using the back-up flight unit. Only the ground templates were exercised and the results were more closely consistent with the results obtained during the flight experiment on STS-41 than during training. Figure 13 shows the results of the postflight session.

Evaluation of the data from the VCS EEPROM and the video cassette tapes recorded during the flight indicate that when Shepherd and Melnick both had good recognition results, "TOO LOUD" messages were recorded in the EEPROM. When Shepherd had poor recognition results, "TOO SOFT" messages were recorded in the EEPROM. This indicates that the majority of the initial problems encountered by Shepherd during the VCS experiment were due to an inadequate input volume level for the voice recognition unit. Figure 12 shows that the major problems encountered by both astronauts were due to omission errors which most likely were caused by the sensitivity of the microphone placement. To address this problem, tests will be performed to determine if incorporating Automatic Gain Control (AGC) into the design of the VCS will eliminate the sensitivity of microphone placement and increase the recognition accuracy rate. In addition, it appears that the lack of consistent training, due to hardware build-up and scheduling, had an adverse effect on the recognition results. A three month idle period in training occurred. However, if voice control is to be part of a spacecraft, then the system must be tolerant of gaps in training.

VCS RESULTS FOR SHEPHERD & MELNICK
GROUND TEMPLATES DURING POST-FLIGHT TESTING

Figure 13

The VCS node structure transition words performed well for both astronauts. To transition from node 2 to node 3, Shepherd used "go" and Melnick used "action." However, when Shepherd used his ground templates, his "Delta" command word would occasionally be misrecognized as the transition word "go." This caused some annoyance since "go" caused the system to transition into node 3. Shephard had to say "activate" to return to node 2. This did not occur in training.

The standby node's transition word "voice command-activate" performed as expected. Not once either in ground training or on-orbit did the VCS inadverently slip into the active listening node 2 while the astronauts conversed. The only problem experienced in the standby node was the feedback message "Ready to activate." When the VCS is initially powered on and a user is enrolled, the system is in the standby node and the feedback message "Ready to activate" appears on the display. When the system has been used and then returned to the standby node, the feedback message "VCS standing by" appears on the display. This discrepancy between the messages caused some confusion the first time the VCS was powered on during session 1. The crew members thought the system was already in the listening node 2 instead of the standby node. The initial message "Ready to Activate" will be changed to "VCS Standing by."

One additional concern is the use of the Shuttle speaker-microphone unit (SMU) on the aft flight deck. It appeared the crew members encountered some minor problems due to uplinked audio messages coming over the SMU while trying to retrain the VCS even though a noise cancelling microphone was used.

6.0 CONCLUSION AND RECOMMENDATIONS

The experiment acquired valuable baseline data on the use of voice recognition technology in space. However, improvements in recognition performance are required before the system can be considered operational hardware on Shuttle. The inconsistency in performance between both astronauts shows that the technology should be able to accommodate users that exhibit varying degrees to the effects of microgravity and training adaptation.

As the results indicate, the recognition scores were lower on-orbit compared to the ground training. This proves the concept that recognition tends to be lower when it is not possible to train in the actual environment. However, in the final on-orbit VCS session, the system was trained in the actual environment with both astronauts reporting 100% recognition. Even though the intent of the experiment was not to test the specific recognition software/hardware algorithm, it is, however, a factor that cannot be overlooked for operational spacecraft applications.

Techniques such as automatic gain control should be investigated to determine if it will reduce microphone placement sensitivity while maintaining good recognition. Improvements in feedback are required to minimize user confusion. Better ways of fine-tuning camera control need further investigation. The astronauts felt that the existing fine-tuning camera controls were too cumbersome to use and that the manual switches are more efficient for that task. Consistent training should be considered for the astronauts to avoid memory degradation of using the system. Ways of creating scenes through macro commands is desirable, where a space operational scene is learned and converted into a one word command. This was strongly suggested by both astronauts.

The astronauts recommend to fly the system again to acquire more data on the performance of the VCS to user adaptation in microgravity. They believe that VCS is a useful method of control on the Shuttle. A follow-on flight will be recommended after the above improvements are incorporated into the VCS.