N94-11539

VISUAL EARTH OBSERVATION PERFORMANCE IN THE SPACE ENVIRONMENT

Human Performance Measurement IV - Flight Experiments

CPT John F. Huth, CAPT James D. Whiteley, CW3 John E. Hawker

ABSTRACT

A wide variety of secondary payloads have flown on the Space Transportation System (STS) since its first flight in the 1980s. These experiments have typically addressed specific issues unique to the zero-gravity environment, and use the experience and skills of the mission and payload specialist crew members to facilitate data collection and ensure successful completion. This paper presents the results of the Terra Scout experiment, which flew aboard STS-44 in November 1991. This unique Earth Observation experiment, specifically required a career imagery analyst as the payload specialist (operator) as part of the experimental design. The primary flight equipment was the Spaceborne Direct-View Optical System (SpaDVOS), a folded optical path telescope system designed to mount inside the shuttle on the overhead aft flight deck windows. Binoculars, and a small telescope, were used as backup optics. Using his imagery background, coupled with extensive target and equipment training, the payload specialist was tasked with documenting: 1) The utility of the equipment, 2) His ability to acquire and track ground targets, 3) The level of detail he could discern, 4) The atmospheric conditions, and 5) Other in-situ elements which contributed to or detracted from his ability to analyze targets. Special emphasis was placed on the utility of a manned platform for research and development of future spaceborne sensors. The results and lessons learned from Terra Scout will be addressed, including human performance and equipment design issues.

I. INTRODUCTION.

Since the very beginnings of the space program, various DOD organizations have shown an on-again, off-again interest in manned surveillance from a spaceborne platform. Unclassified literature indicates two of the earliest programs were the Dyna Soar and Manned Orbiting Laboratory (MOL) programs of the 1950s and 1960s, respectively [1]. Both of these programs were purportedly cancelled due to cost overruns and the political climate, before being tested. From the early 70s, when the Apollo program was winding down, until the beginning of the Shuttle program in the 80s, the DOD showed little interest in such programs. Whether this was due to opportunity or other reasons is unclear. Interest by the services surged in 1985 with the beginning of the Military-Man-In-Space (MMIS) program. The objective of the MMIS program is to capitalize on man's unique decision making abilities, and apply these skills to satisfy DOD objectives.

Various experiments were proposed by the military services at the beginning of the MMIS program. Included in the list of experiment proposals were three military earth observation experiments; one from each of the services. The three experiments -- Battleview, Moses, and Terra Scout were proposed by the Air Force, Navy, and Army, respectively. Terra Scout was unique in that the experiment required a payload specialist (PS) who was a military imagery analyst and would use specifically designed optics, rather than a career astronaut provided with off-the-shelf optics. The drawbacks to this approach were numerous, the optics had to be designed and tested, and using a PS meant a greater shuttle performance margin requirement as well as fighting numerous political battles. As one might predict, the other two earth observation experiments were flown prior to Terra Scout. Battleview, with Army input (known as Terra View), Moses, and another experiment called Space Debris were combined together as a Tri-Service experiment call M88-1. These experiments were conducted on STS-28 in August 1989. It was our opinion, after reviewing the results from this flight, that we were on the right track. The crew had reporting seeing ships, large swept wing aircraft, and the crew commander said with slightly better optics he would be able to see trucks on a highway. They also found that large aperture optics (a 6" Celestron) were useless because of the poor optical quality of the shuttle windows. This finding was later supported by optical tests of the space overhead windows by Armstrong Aeromedical Research Laboratory (AAMRL) and the Aerospace Corporation [2,3].

II. EXPERIMENTAL SETUP.

The primary optical equipment selected for the Terra Scout experiment was the Spaceborne-Direct View Optical System (SpaDVOS) (see Fig 1). The SpaDVOS was developed by AAMRL, with enough funding from the Air Force and Army to build two flight units. The SpaDVOS was originally designed for human factors experiments by AAMRL and was first flown on STS-38 in December 1990. Using the comments from the astronauts who used the SpaDVOS on-orbit, a number of hardware modifications were made to prepare for the Terra Scout experiment.

The original purpose of the Terra Scout experiment was to collect data which could be used to determine the ability of the PS to collect valuable information in real time. During the seven year development of the experiment, the objective evolved to include a variety of R&D issues such as: testing the flexibility of the man-in-the-loop, estimating how well the Soviet cosmonauts could see from their manned platforms, identifying potential utility/benefit of real-time observations to the DOD (e.g., crisis augmentation), the utility or advantages of live-color analysis, and the utility of the Shuttle as an R&D platform for future experimentation.

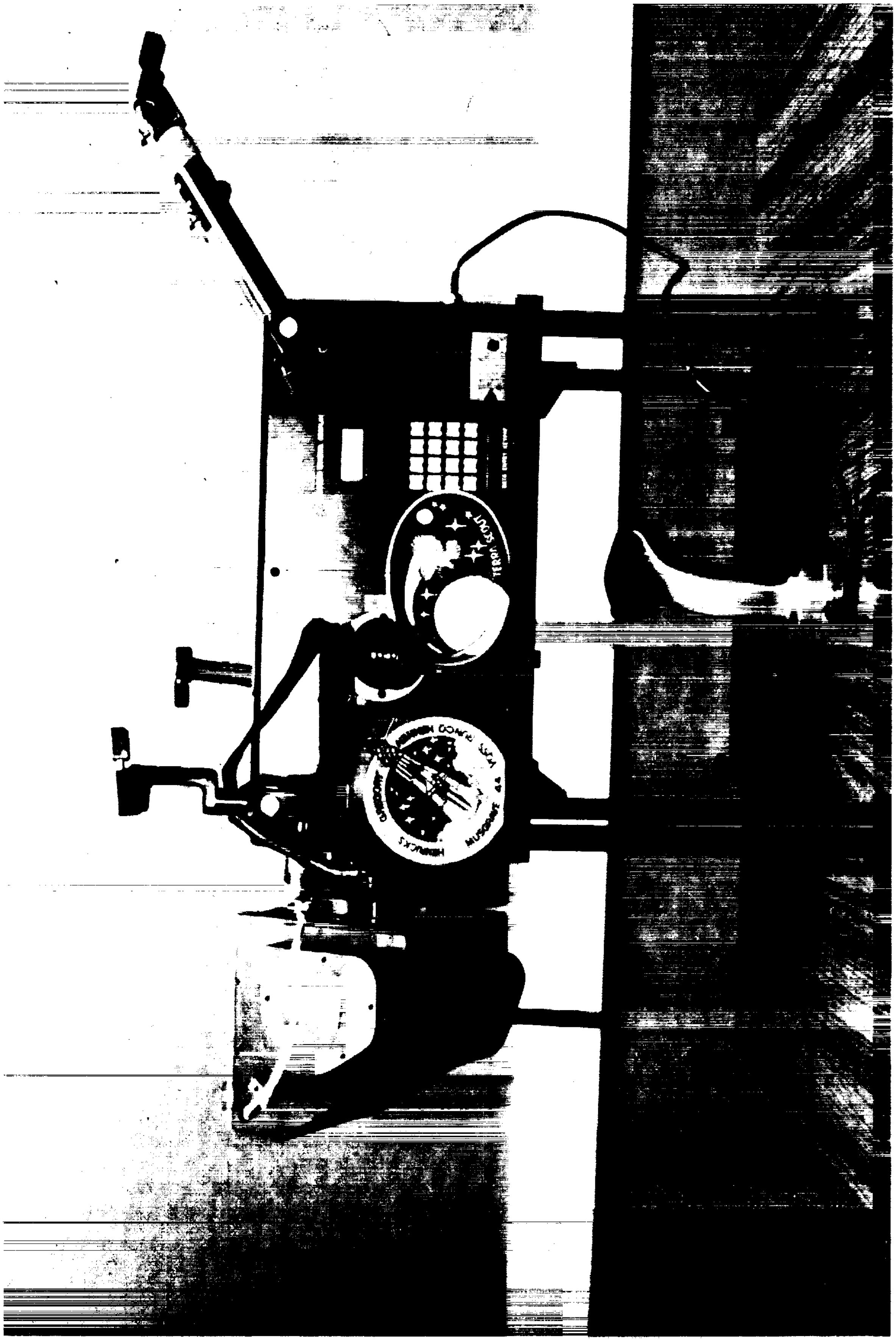

Figure 1

The general approach for data collection used by the PS was to mount the SpaDVOS optics in the overhead, aft flight deck windows using the window shade clamps. Next the SpaDVOS was connected to the 28VDC orbiter power and orbiter Video Tape Recorder (VTR) system then switched on. The PS then initialized the system by moving the tracking mirror forward/aft and side to side. Target data was entered for up to three targets. This data included the Mission Elapsed Time (MET) of closest approach to the target, the off-nadir angle or direction to the target, and the orbiter altitude and velocity at that MET. By entering this information on a keypad, an internal computer provided the operator pointing cues to the target from one minute prior to acquisition until visual loss of the site. These cues were displayed by two LED displays in the eyepiece providing cross-track and along-track data. When these LED displays were "zeroed-out" the operator was assured that his target was in the telescope's field of view. While target acquisition was strictly manual, once the target site had been acquired, tracking could be done manually, or in a semi-automated mode using a joystick to control the along-track velocity of the tracking mirror. While the target was being tracked, the operator could zoom in or out and change the aperture setting (f-stop) with two handles on the bottom side of the SpaDVOS (see Fig 2). Three eyepieces were provided so the operator could select the best magnification for the target site. These covered a magnification range from 4X to 67X. Each of these eyepieces, as well as other SpaDVOS functions, were tested during the characterization pass over the first ground site.

The way that the SpaDVOS unit was able to capture light and record on a video tape is as follows:

> The optical path of the SpaDVOS has a beamsplitter just before the light is reflected into the eyepiece. The beamsplitter routes half the light to the eyepiece and the other half to a Charge Coupled Device (CCD). The CCD image was recorded using the obiter VTR system. Since the CCD image is not magnified by the eyepiece, the visual and recorded images have different scales. The purpose of the recording was to visually confirm the operator was in the target areas, and record his verbal comments on the audio track. As alternate optics, the PS also had a pair of 14X70 Fujinon binoculars and a 15-60X Bausch & Lomb spotting telescope.

The PS was to analyze both pre-planned and ad hoc targets. Pre-planned targets were selected during mission planning, and the PS was familiar with these by studying target folders. These folders were taken aboard for reference and refresher prior to target acquisition, and to annotate comments about target status after a target pass. Pre-planned targets included a variety of military and geographical targets, as well as four large resolution grid targets (see Fig. 3). The pattern of disks on the

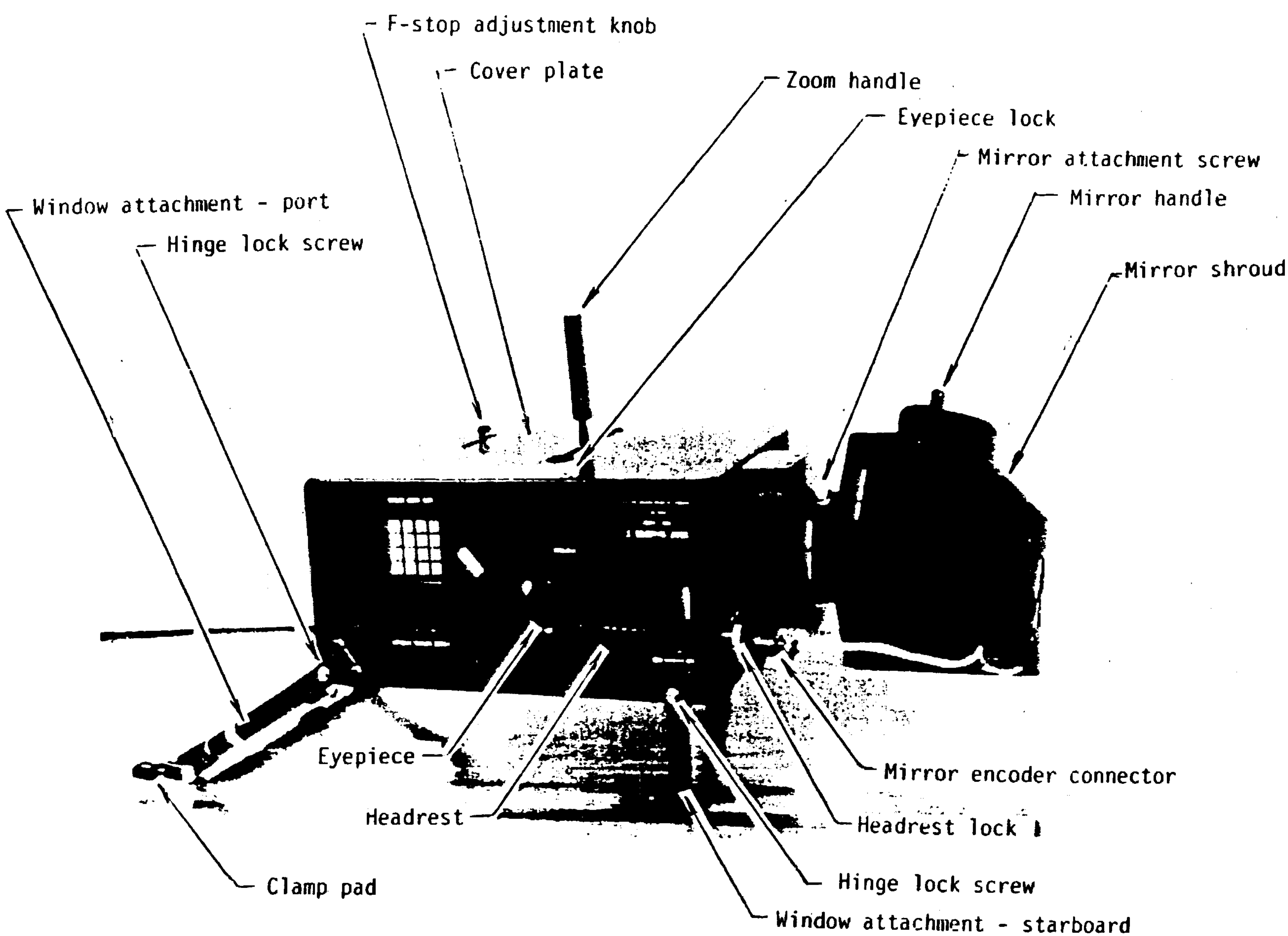

Figure 2 Fully Assembled Unit.

resolution grid, which are known as Blackwell disks, were changed after each shuttle overflight by teams on the ground. They also measured the illumination (contrast) and collected weather measurements at the four resolution sites. Ground truth for the other sites was provided by national technical means. Ad hoc targets were targets which were uplinked to the PS during the mission, and for which no target folders existed.

The PS trained for the experiment by extensive study of target folders, becoming familiar with the hardware, and by using the Flexible Image Generation System (FIGS) at AAMRL. The FIGS simulates what he would see looking at the earth with SpaDVOS at shuttle altitudes and velocities. Additionally, he had the opportunity to use the SpaDVOS during testing on a Lear Jet and several "Zero-G" (KC-135) flights.

Terra Scout was manifested for flight in June of 1990. The flight assigned was STS-44, which was scheduled for an early 1991 launch. While things started to pull together during the preparation for launch, there were several technical and operational concerns. Window tests on spare overhead windows made the case for smaller aperture optics, such as SpaDVOS, to be near optimal. The concern was what the usable magnification would be even with a near optimal aperture [2,3]. Several improvements were made to SpaDVOS as a result of STS-38. The eyepiece focus adjustment was redesigned and additional eyepieces were tested and added to better cover the magnification range. An along-track motor drive was added to the SpaDVOS unit, despite the short time before launch. This allowed smoother tracking than could be done manually. There were also indications from both the STS-38, as well as the "Zero-G" flight, that having the PS stable during target acquisition and tracking could be a problem; a means of restraining him with a harness and straps from the treadmill was devised.

A primary human factors concern was if the PS would experience space sickness and how this would effect his skills to conduct the experiment. Atmospheric effects were another key concern. Not only should you count on almost doubling the number of opportunities you need to account for weather, but the effects of recent volcanic activity, oil fires, and rain forest burning were evident in the sunsets. We were curious about the effect this would have on our data collection. A study done for us by the Army Research Institute in 1987 estimated we would need 20 good observation opportunities for statistical significance [4]. Under the experimental design we were to make comparisons between our spaceborne observer and a ground-based observer, who was provided with similar data to analyze. Taking 20 as our minimum sample size, and with 42 opportunities in our flight plan, we were near where we needed to be, using the rule of thumb for weather. However, the other factors were still complete unknowns.

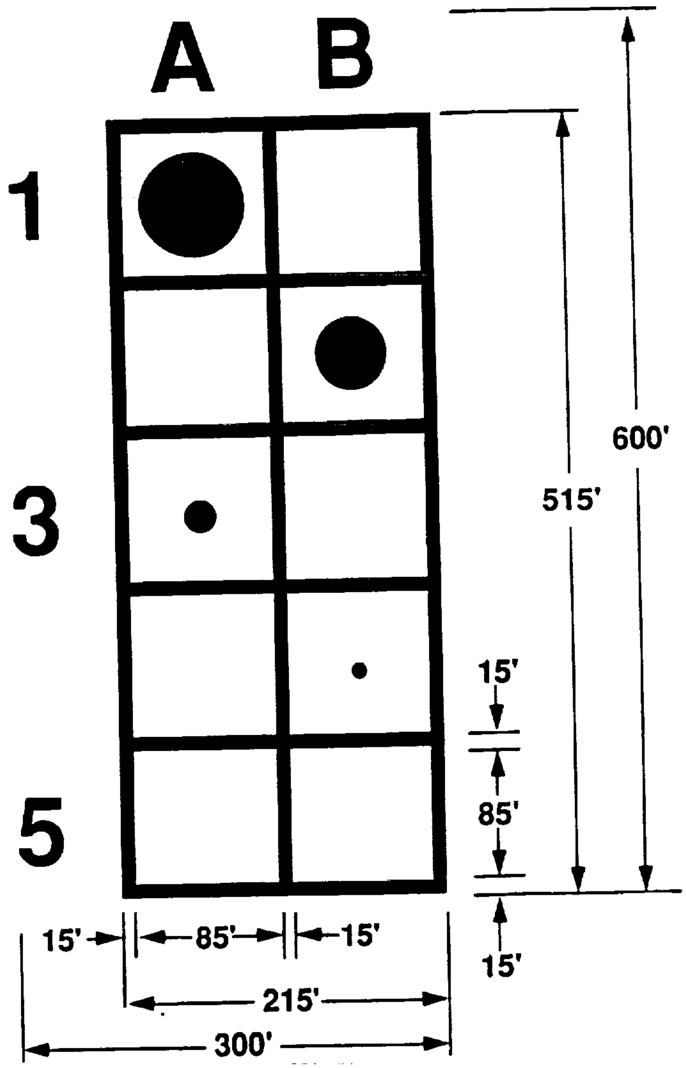

Figure 3

III. RESULTS AND DISCUSSION.

On 15 Nov 91 we conducted our L-5 (5 days prior to launch) checkout of the experiment hardware, the last check before it was moved to the Vertical Assembly Building (VAB) and then into the middeck lockers. STS-44 launched just after 6:30 p.m. on 24 Nov 91. The next day, on orbit 17, was the first scheduled observation opportunity. This was a characterization pass on a resolution target. The pass was successful and the resolution grid and largest circles were acquired. However, several minutes later, on another resolution target pass the cueing system malfunctioned. It was discovered that by cycling the power, the anomaly could be corrected. This problem never occurred prior to flight, and could not be duplicated nor the source discovered afterward.

The calibration passes, which were done during the early part of the mission, indicated that the best eyepiece to use was the 21mm at maximum zoom. This provided a magnification of approximately 30x.

Another anomaly, which occurred was the lack of smoothness in the tracking. This also had never occurred during ground or Zero-G testing. Although the initial thought was that launch vibrations may have damaged the hardware, a post-mission analysis of the hardware and discussions with the PS and commander made us suspicious that the hardware may have been damaged between L-5 and flight. This possibility was based on the two anomalies discussed, as well as damage to the eyepieces and the outside of the SpaDVOS. None of these conditions existed prior to launch, but were present on-orbit. Damage to eyepieces and on the outside of a piece of hardware, that are surrounded by foam packing, would not be expected by normal launch vibration, nor were they experienced with the hardware on STS-38 or with the M88-1 hardware on STS-28 or STS-44.

The hardware anomalies, however, did not significantly impact the mission objectives. Rather, the combination of window quality and atmosphere had the most adverse effects. The windows limited the effective magnification of the 9mm eyepiece, such that it was not usable in full zoom. However, atmospheric conditions were the greatest detractor from the experiment. STS-44 was described as one of the cloudiest missions in shuttle history. Additionally, the combination of environmental factors, which were responsible for recent spectacular sunsets, also degraded our observation capabilities. Satellite data analyzed by the Space Shuttle Earth Observation Office indicated that the atmosphere over our resolution sites were well below optimal. Also, the comments recorded by the PS indicated that the resolution sites were typically clearer than the other ground targets. Comments by the veteran astronauts on the flight supported the PS comments and the satellite data analyzed by NASA.

On day seven of the mission, a malfunction in the space shuttle's back-up IMU forced an early termination of the mission. Not only were there eleven more opportunities planned, but the PS and MS for the M88-1 experiment who had previously been competing for window space, managed to find a way of using both experiments in the window simultaneously. This would have provided more observation opportunities for both experiments, as well as other potential synergistic outcomes. In the final tally only eight of the observation opportunities provided enough data for adequate analysis.

Our concerns about the stability of the observer in the eyepiece turned out not to be an issue as the PS had no problem with stability. Also, concern over the space sickness effects on the PS satisfactorily resolved itself as the PS experienced no space sickness. One issue that did arise during the course of the experiment was the complication involved in communication with the PS. Trying to resolve anomalies to get experiment status would be much clearer if the PI were allowed direct communication with the PS/MS.

With the small sample size, statistical analysis was difficult, at best. Even without statistical significance, we believe that with the data collected, we have successfully met our objectives. The ability of the PS to dynamically acquire targets other than those which were provided to him in real time, detect target motion, work around or fix hardware anomalies, and use his decision making abilities to streamline the conduct of the experiment, demonstrated the flexibility and utility of the man-in-the-loop. These were all worthwhile data points which are hard to quantify.

The SpaDVOS was very capable of providing target acquisition and tracking capability. Under certain conditions, the PS reported seeing the disks down to 24ft., as well as identifying the 15 foot wide grid lines outlining the grids. Note that grid lines being long, linear features aids in their identification. His observations also indicated the strong correlation between resolution and the angle off nadir to the target. Most of the opportunities did not allow sufficient resolution for analysis primarily due to atmospheric and window conditions limiting effective magnification. Based on previous window tests, as well as the limited number of good observations we did make, it seems unlikely that good resolution through the windows would be consistently available to do any analysis further than identifying surface ships or large aircraft. These conditions combined with shuttle orbital parameters make tactical target detection serendipitous at best. This is not to say that further testing of other available optics should not be done, as the variables which effect in-cabin resolution and their relative effects are not sufficiently understood. Hardware with characteristics similar to

SpaDVOS would be useful for geological and weather applications, however, the device should have a single optical path. This would preclude poor video recording caused by optimizing the aperture for the observer, and leaving insufficient light for recording images.

While the resolution needed for detailed target analysis was not sufficient, the level of detail that was available from the SpaDVOS and the 14X70 binoculars did allow the PS to observe ships and large aircraft. Observations of this type activity does have direct impact on operations security. Just as the Soviet's have conducted extensive testing on color vision, there are strong indications that their manned orbiting vehicles have been used to conduct extensive military experiments. These experiments have most likely included the evaluation of man's ability to identify, track, and locate targets and R&D of advanced reconnaissance and surveillance systems [5]. Knowing they have windows in their space station and given their interest in exploiting their space capabilities, it is not unreasonable to assume that their windows are likely of optical quality. This would provide them with an "in-cabin" resolution capability much better than our current capability. This should be well considered for our future manned systems if we plan to test systems for military or environmental purposes.

The capability of viewing a scene in color seems to be a significant contributor to target acquisition, tracking, and analysis. This is based on comments from the PS, which support the comments of other cosmonauts and astronauts. The phenomena of color vision and color observation from orbit has been investigated extensively by the Soviet's [6] and warrants further analysis. It is the spectral content of a ground scene which we are planning to exploit in future experiments.

The major advantage in using the current shuttle program for military earth observation would be to test advanced sensors in the payload bay. For testing advanced sensors the shuttle provides:

- A controllable platform at many available altitudes and attitudes.

- Easily returnable payloads.

- Testing in the space environment.

The advantages of using a PS for specific experiments are significant when a particular skill is needed. A Principal Investigator (PI) should always use the most qualified person for the task. Therefore, he is better and more intensively trained on experiment specific tasks. He is more available for feedback, providing his feedback to the experimenters in a common language, making it easier to relate his experiences. Additionally, our PS was completely integrated into the crew, becoming involved with other experiments as well as Terra Scout. This worked to the advantage of everyone. This was particularly true of the medical experiments, which will further our understanding of physiological effects of spaceflight on the human body.

It is our conclusion that the experiment was an overall success and related follow-on experimentation, research and development should be pursued.

REFERENCES

[1] Timothy D. Killebrew, "Military Man In Space: A History of Air Force Efforts to Fund a Manned Space Mission," Air Command and Staff College, Report #87-1425, May 1987.

[2] Harold S. Merkel, Harry L. Task, "Optical Test of the Space Shuttle Overhead Windows," AAMRL Report AAMRL-TR-90-024, May 1990.

[3] Karen P. Scott, "Space Shuttle Overhead Windows, Optical Tests," Aerospace Corporation Report #TR-0091(6508-21)-1, June 1991.

[4] George W. Lawton, "Suggested Terra Scout Experiment Plan," Army Research Institute Working Paper WPHUA 89-02, January 1989.

[5] Johnathan Litchman, "The Soviet Manned Space Program in Support of Ground Forces," How They Fight, DIA Document #ATC-WP-2600-034-90, January-March 1990, pp. 19-21.

[6] Vladimir V. Vasyutin, Artur A. Tishchenko, "Space Coloristics," Scientific American, July 1989, pp. 84-90.

TEST PILOT PERSPECTIVE ON HUMAN PERFORMANCE IN FLIGHT

Maj. Pete Demitri

Abstract unavailable at time of publication.