JSC-18553

STS-4 Orbiter Mission Report

SUPPLEMENT

NOVEMBER 1982

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

JSC-18553
Supplement

STS-4 ORBITER

MISSION REPORT

SUPPLEMENT

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November 1982

INTRODUCTION

The supplement to the STS-4 Orbiter Mission Report (JSC-18553) contains the remaining closed problem reports that were open when the report was published, plus the STS-4 crew report. This supplement plus the Orbiter Mission Report complete the reporting process for STS-4.

FLIGHT TEST PROBLEM REPORT

NO. STS-4-1

Statement of problem: TPS (Thermal Protection System) Tile Damaged by Prelaunch Hail Storm

Discussion: The night before the STS-4 launch, a rain and hail storm occurred in the area of Launch Pad A. The hail extensively damaged the Orbiter surface TPS tiles. Some of the damage on the right wing was repaired with a densification slurry prior to launch. The severity of the rain storm accompanying the hail resulted in significant amounts of water being absorbed by the hail-damaged tiles plus possibly other tiles. During the on-orbit phase of the STS-4 mission, the vehicle was oriented with the bottom toward the sun to successfully dry out the wet tiles. This was required to preclude coldsoak damage to the tiles as occurred on the right wing glove during STS-2. Postflight inspection showed no indication of tile ice damage.

Conclusions: While on the pad, the Orbiter is susceptible to significant surface damage from hail storms and water absorption from rain storms. The on-orbit dry-out of the tiles is effective in preventing tile ice damage. However, the attitude constraint of bottom-to-sun does have a significant impact on payload operations.

Corrective action: The hail-damaged tiles have been repaired for STS-5 using standard repair techniques. The RSS Roll back from the vehicle has been delayed. Modifications to the RSS are being made that will provide additional protection to the Orbiter.

For STS-5, a witness panel consisting of 20 HRSI tiles will be exposed beside the Orbiter on the mobile launch platform. Tile weight of the witness panel before launch will be used along with DFI data to make a bottom-to-sun drying decision.

The response of the tile to ascent heating and the cooling effects of ice sublimation on the tile, will be used to determine the amount of water in the tiles. Ascent and on-orbit DFI data will be used to make this determination. Analysis indicates that the -ZLV attitude will not allow the tiles to get cold enough to cause fracture problems. However, in the starboard sun attitude, tile temperatures as low as -70° F to -80° F can be expected. Should analysis of DFI data indicate that the water remaining in the tiles at initiation of starboard sun could cause fracturing, then some period of bottom of sun will be required to bake out the water.

APPROVED [signature] 10-13-82
A. Aldrich — Date

W.H. 10-5-82

Effect on subsequent missions: Excessive rain storms and/or hail storms may impact on-orbit operations for drying the tiles. Also, water absorption by the tiles will result in unknown lift-off weights, and may require additional turnaround time to repair hail-damaged tiles or dry out water-soaked tiles.

[signature] 10/4/82 [signature] 10/4/82

Personnel assigned: R. L. Dotts/ES32; C. J. Walsh/WC6

Resolution: CLOSED 10/06/82

FLIGHT TEST PROBLEM REPORT NO. STS-4-4

Statement of problem: Reaction Control System (RCS) Engine F1L Oxidizer Leak Indication

Discussion: Just after the OMS-1 maneuver, RCS thruster F1L developed an oxidizer leak that reduced the leak detector temperature measurement from 79° F to 30° F in 30 seconds. RCS thruster F1L was automatically deselected at 178:15:16:38 G.m.t. because of the low oxidizer-injector leak-detector temperature. The crew went through the malfunction procedures and determined that the leak was not large enough to warrant closing the manifold 1 isolation valves. The leak apparently stopped shortly after the thruster was deselected as indicated by increasing leak-detector temperatures. Approximately 3 hours later, the flight controllers instructed the crew to close manifold 1 which then deselected the other manifold 1 engines (F1F, F1D, and F1U). On day 3, the manifold was repressurized. Manifold 1 pressures indicated that the manifold had stopped leaking and there was no indication of leakage on the leak detector. Thruster F1L was test fired and then used for the remainder of the mission without any further indication of leakage. However, the first night after the flight, the thruster cooled to 59° F and began leaking again as the heaters had not been turned on.

A helium leak check at the vendor indicated very low leakage at both ambient and cold temperatures. A detailed inspection found three small dark particles of iron nitrate and a small sliver of nylon on the valve seat. The size and shape of the nylon particle corresponded with the depression on the teflon seal. The nylon particle, which appears to be a sliver from a nylon parts bag, was most probably introduced during the manufacturing process. The procedures for purging, flushing, and drying during testing at the vendor were improved to eliminate iron nitrate formation. Multiple cutting of nylon parts bags along the same line may produce slivers and will be eliminated.

Conclusions: Thruster F1L leaked oxidizer during the flight and the leak detector deselected it. The leakage was caused by contamination that showed up when the engine was fired since F1L was a new engine for this flight. The nylon particle probably was embedded in the teflon seal and allowed the leakage to stop; however, the leakage started again after the flight when the cooler temperatures caused the seal to shrink.

Corrective action: The F1L engine was replaced for STS-5. Valve processing procedures have been improved to eliminate contamination during assembly and testing.

APPROVED A. Aldrich for 10/15/82
Date

Effect on subsequent missions: None.

Personnel assigned: D. R. Blevins/EP4; R. J. Ward/WA3

Resolution: CLOSED 10/20/82

FLIGHT TEST PROBLEM REPORT NO. STS-4-5

Statement of problem: APU (Auxilary Propulsion Unit) 3 High Lubrication Oil Pressure

Discussion: Prior to STS-4, the gearbox seal on APU 3 was known to be leaking. The decision to fly with this condition was made because it was believed that a small amount of contaminant on the rotating seal would clear after APU startup, and if it did not, the leak would not be of sufficient size to cause an APU malfunction during ascent.

The APU experienced high lubrication oil pressure accompanied by low flow during most of the STS-4 mission. During ascent when the filter clogged, the pressure reached 100 psid, then dropped to 50 psid for a short interval after which the pressure returned to 100 psid. The pressure drop to 50 psid was the result of the filter bypass valve sticking temporarily in the open position. This has been verified during postflight testing.

The lubrication oil and filter were analyzed for contaminants that would have caused the filter to plug. The lubrication oil sample had the highest total filterable solids ever detected after a flight.

The filter was still plugged after the flight. A bench test of the filter showed that the filter developed a pressure of 150 psid at 2 gpm (normal filter flow is 5 psid maximum at 4.2 gpm). An analysis of the material found on the filter showed it to be 98-percent pentaerythritol, 1.6-percent carbon, and traces of several other elements.

The pentaerythritol is a substance formed when hydrazine penetrates the gear box and reacts with the lubrication oil. In past cases of pentaerythritol contamination at about 200° F lubrication oil temperature, the pentaerythritol would go into solution and the pressure would be lowered. This time, the filter never cleared. Because the filter was so clogged with pentaerythritol, there was not enough lubrication oil flow through the filter to provide unsaturated oil for the pentaerythritol to go into solution.

Conclusions: The high lubrication oil pressure (low flow) during STS-4 was caused by hydrazine penetrating the gearbox and forming a crystalline substance which then clogged the filter. The filter never unplugged throughout the flight, therefore the pressures remained high.

Corrective action: The APU was removed and replaced with an uncontaminated APU with a good gearbox seal. In addition, KSC has revised their flushing and servicing timelines so that the gearbox is not empty for long periods of time. (The carbon nose piece seal is more likely to leak if allowed to dry.)

Long term fixes include an improved seal design and the selection of an oil which will not percipitate undesireable contaminants when mixed with hydrazine.

APPROVED [signature] 10 13-82
A. Aldrich Date

W.T.H. 10-5-82

Effect on subsequent missions: None.

[signatures] 10/4/82

Personnel assigned: R. J. Lance/EP4; C. J. Walsh/WC6

Resolution: CLOSED 10/06/82

FLIGHT TEST PROBLEM REPORT NO. STS-4-7

Statement of problem: Hydrogen Tank 4 Heater "A" Failed.

Discussion: KSC postflight troubleshooting located an open circuit in Tank 4 heater "A" and the heater assembly was returned to the vendor for failure analysis.

Teardown and inspection of the heater assembly showed a 0.020 in. gap in the nickel wire within 1 inch of the nickel-to-nichrome weld joint. Metallurgical analysis of the fracture area indicates the failure was brittle and most probably due to a stress rupture in an area of large grain growth caused by the high temperatures during the manufacturing process.

Failure history (i.e. 5 of 224 heater welds) shows that all failures occur early in heater life. The tank 4 heater failed during the 3rd cryo cycle. Two of the OV-102 tanks have 8 cryo cycles and one has 9 cycles. All five failures occurred in less than four cryo cycles.

Conclusions: The open heater was most probably caused by a stress failure in the heater element that was initiated by the manufacturing process. Cryo tanks remaining in OV-102 have sufficient cryo loading cycles to be acceptable for STS-5.

Corrective action: Hydrogen tank 4 is not required for STS-5. Additional cryo cycle screening of uninstalled tanks is planned and efforts to refine the heater element design fabrication process have been initiated.

APPROVED ____ A. Aldrich ____ 10-13-82 Date

W.H. 10-5-82

Effect on subsequent missions: None.

C.A. Walsh 10/5/82

Personnel assigned: T. L. Davies/EP5; C. Walsh/WC6

T. L. Davies/EP5

Resolution: CLOSED for STS-5 10/06/82

FLIGHT TEST PROBLEM REPORT

NO. STS-4-8

Statement of problem: VTR (Video Tape Recorder) Recorded Tape Frames Out of Synchronization During Playback on Monitor 2.

Discussion: The onboard-recorded video tapes could not be properly synchronized with the console monitor no. 2 when playback in the "direct" source mode was attempted. Post-mission testing at KSC indicated that the "panel" mode worked properly.

Tests at the vendor isolated a failed CMOS (Complementary Metal Oxide Semiconductor) switching chip in the monitor input circuit. The chip failed to switch to the "direct" source mode. The failed chip was replaced and the monitor operated properly. Failure analysis on the CMOS chip is continuing. Failure of semiconductor chips has not been a generic problem during the flight test program.

Conclusions: Tests at the vendor located a failed CMOS switching chip in the monitor input circuit.

Corrective action: The monitor was replaced on OV-102. The failed CMOS switching chip was removed and replaced at the vendor.

APPROVED: for A. Aldrich 10-6-82 Date

10-5-82 10/5/82

Effect on subsequent missions: None.

10-5-82

Personnel assigned: B. C. Embrey/EE2; R. J. Ward/WA3 10/5/82

Resolution: CLOSED 10/06/82

FLIGHT TEST PROBLEM REPORT

NO. STS-4-22

Statement of problem: Water Intrusion in Forward RCS Thrusters

Discussion: Prelaunch pictures as well as evaporative cooling of the leak detectors during ascent indicate that water was trapped behind the protective paper covers of engines F3D and F1L. The lowest temperature seen on these 2 engines during ascent was 39° F.

Evaporative cooling of seven other engines without paper covers also indicated the presence of water. The lowest temperature seen on these engines was 47° F.

The concern with water in the engines is deselection of that engine due to freezing in the chamber pressure (Pc) tube or unstable combustion with freezing in the injection ports.

An evaluation has been conducted to determine the impact of launching after a rainstorm in which the vehicle was exposed on the launch pad with the following results:

1) The likelihood of a paper cover leak is small. Only 2 of 11 covers leaked on STS-4 after severe rain and hail. No leaks were seen on STS-2 after rain.
2) No positive inspection to determine the presence of water can be done with the RSS rolled back. For STS-5, the RSS roll back will be delayed until T-3 hours.
3) If a paper-covered engine were to leak it is unlikely that the water would freeze. The lowest temperature seen during ascent on 9 engines with water on STS-4 was 39° F. The lowest temperature of any engine at launch on the previous shuttle flights was greater than 70° F.
4) The only time-critical use of the paper-covered engines is for an abort-once around underspeed, or return-to-launch-site abort. For all other flight conditions time permits the reselection of a engine deselected due to freezing in the Pc tube or the deselection of a frozen engine.

Conclusions: The water in engines F3D and F1L was due to a leak in the silicone seal between the paper cover and the engine bell. Launching with water in RCS engines is an acceptable risk with paper covers installed.

Corrective action: The RCS OMI (prelaunch procedures) for STS-5 will include detailed installation and inspection of the RCS paper covers. The RSS rollback for STS-5 has been delayed to T-3 hours, thus lessening the time for exposure to rain. Additional rain protection for the vehicle has been approved for future implementation.

APPROVED ______________________ 10-13-82

A. Aldrich — Date

Effect on subsequent missions: None.

10/8/82

Personnel assigned: Carl Hohmann/EP4; C. J. Walsh/WC6

Resolution: CLOSED [redacted]/09/82

FLIGHT TEST PROBLEM REPORT — NO. STS-4-34

Statement of problem: The UHF Extravehicular Activity RF Communications Were Noisy While Donning the EMU

Discussion: During the EMU (extravehicular mobility unit) demonstration activities, the Commander reported that RF communications were poor due to high background noise. Postflight reviews indicated that the noise disappeared 30 seconds after egressing the EMU airlock mounting fixture. Hardware tests revealed no problems, but the same noise could be reproduced by unsquelching the EMU receivers. In previous tests, the intermittent metal-to-metal contact between the EMU and other surrounding metal objects caused high background noise levels in the EMU receivers. The EMU fits loosely in the airlock mounting fixture to allow easy ingress and egress. In zero-g, the EMU floats in these mounts, making intermittent contact with the mounting fixture.

Conclusions: The noise was probably due to the reradiation of the EMU RF signal caused by the intermittent contact between the EMU and the mounting fixture with the resulting unsquelching of the EMU receivers.

Corrective action: For STS-5, the crew will switch to the hardline communications mode via the umbilical while the EMU is in its airlock mounts, if the problem recurs. A long-term fix is being evaluated to insulate the mounts and break the intermittent conductive path.

APPROVED ____ A. Aldrich ____ Date 10-6-82

Effect on subsequent missions: None.

Personnel assigned: P. Shack/EE3; R. J. Ward/WA3

Resolution: CLOSED 10/06/82

JSC-18553

APPENDIX

STS-4

CREW REPORT

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Capt. Thomas K. Mattingly, USN
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November 1982

APPENDIX - STS-4 CREW REPORT

1.0 INTRODUCTION/SUMMARY

One week aboard the Orbiter "Columbia" convinced the STS-4 crew that in many ways the Shuttle really is the DC-3 of the space age. This analogy is most appropriate when considering their respective roles in revolutionizing society's concepts of how to apply advanced technology to solve contemporary problems. Two major differences, however, stand out and are responsible for much of this report. These are that, like modern aircraft, the Shuttle will be an evolutionary design, and that the Shuttle is a true spaceship and therefore, must integrate many features of both ships and aircraft.

Contemporary airframes served for decades in their original shape, yet their efficiency and effectiveness are increased enormously through avionics and propulsion improvements. The STS-4 crew believes this same trend will be demonstrated over the life of the Shuttle and, therefore, the crew has tried to indicate areas where evolutionary growth may be appropriate.

Ships are designed to be relatively self-sufficient for extended periods of time. Aircraft, on the other hand, are typically extensions of a larger base. A seagoing ship must provide not only working space for the crew, but must also provide a long-term self-contained habitable environment. Aircraft leave as much of the crew services on the ground as possible to improve performance. The spaceship must provide a compromise between traditional aircraft and ship strategies. Weight and volume considerations are as critical to a spaceship as they are to any aircraft; however, the crew's health and efficiency are equally significant in executing both seaship and spaceship missions. The one area in which the spaceship is more critical than either its aircraft or ship predecessors is that of time management. Orbital time is expensive and must be used as efficiently as possible. Many of the STS-4 crew observations, therefore, pertain to improving habitablity and crew efficiency.

STS-4 was the final dedicated flight-test mission prior to embarking on the operational employment of the Shuttle. Typical flight-test programs for aircraft include a formal segment dedicated to the conduct of an operational suitability evaluation. The STS-4 crew attempted to evaluate operational characteristics to the maximum extent possible within the constraints of the formal engineering test objectives. The scope and number of observations included in this report reflects this approach and more, therefore, than would normally be expected from a mission as nominal as STS-4.

1.1 REPORT FORMAT

Four sections present the observations recorded during the period surrounding the STS-4 mission. To provide some organization to these observations, they have been arranged as follows:

a. Crew training

b. Flight data file and mission planning/execution

c. Vehicle systems (hardware and software)

d. Operational observations

Wherever possible, these sections attempt to avoid restating those events and anomalies which are known to appear in other organization mission summaries. Therefore, this report does not contain a mission chronology and may not even address the most significant happenings.

1.2 MAJOR CREW IMPRESSIONS

A "magic machine" is the only way to describe the Shuttle from a crewman's viewpoint. In spite of daily involvement in the Shuttle development from award of the "authority to proceed" through the OFT (orbital flight test) program, the crew was still impressed with the tremendous capability that has been built into this element of the STS (Space Transportation System). Only three events involving the vehicle design marred the otherwise flawless performance. The flight crew's perception of these events and how they may affect future operations are reflected in the following paragraphs.

1.2.1 Ascent

Ascent performance is the key to the long-term success of the STS. STS-4 carried a relatively light cargo, flew a 28.5° inclination and shaped its ascent profile to accommodate demonstrated main engine and solid rocket booster performances. Nevertheless, a reconstruction of the STS-4 ascent phase indicates a great deal of uncertainty still remains in describing the contribution of each element in this complex scenario. It appears that STS-4 had less margin than anticipated. The implications of this finding, if it proves correct, will significantly influence the ascent/abort strategies as well as how ambitious we can be in putting payloads into orbit. The possibility that STS-4 carried a significant amount of water into orbit in the tile system may have implications for orbital timelines and TPS (thermal protection system) integrity as well as ascent performance.

1.2.2 Payload Bay Door

The port PLBD (payload bay door) apparently hung up on the door seal during a thermal-gradient door-closure test. The engineering community is working this event and should have it understood prior to the next mission. Preliminary reports indicate that the aft bulkhead/PLBD interface does not have as much tolerance for mechanical mismatch as the rest of this system. Distortions, such as encountered during this test, might seriously jeopardize entry and the success of an EVA (extravehicular activity) to correct this condition is highly questionable. It seems essential that conditions such as encountered during STS-4 must be prevented, not fixed.

1.2.3 Landing

Landing and stopping the Orbiter on a runway is a precise task requiring careful control and accurate information. By design, the STS-4 landing task provided large margins for execution error and data uncertainties. In spite of extensive crew training for the scheduled submaximum braking test, the crew did not achieve the target level of deceleration and could not maintain a constant level of braking. Landing weights will most certainly increase with the TAL (trans-Atlantic) abort weight, thus requiring a perfect maximum performance stop to use the available runways. The achievable envelope of Orbiter braking performance must be demonstrated before practical mission planning can be continued.

1.3 PAYLOAD INTEGRATION

The support of payloads provided by other than NASA was a new opportunity. The procedures employed by all parties worked well and made incorporation of the CFES and DOD payloads into this mission a pleasant experience. The dedication and competence of these non-NASA participants was of the same high caliber as we have come to expect from NASA itself.

1.4 KEY LONG-TERM OPERATIONAL CONSIDERATIONS

Three key observations appear to warrant special attention as we move into the operational era with the Shuttle.

Personal morale and dedication have been the real reason this and previous manned space programs have been so successful. The strict attention to detail that has brought us this far will be just as necessary in 1990 as it is today. Flight crews have never, and will never, have any problem with personal motivation; however, the pace of the future requires that particular attention be given to finding challenging career patterns for all of those who support crew and vehicle preparations. There is no evidence today that NASA personnel have lost any of their traditional dedication or skill. Nevertheless, sustaining the current pace without burning out our work force deserves attention at all management levels.

Training flight crews will always be a long and demanding process. Until the vehicle operations and scope of our procedures can be simplified, the only hope for reducing this training task is improved efficiency in the training process itself. Both of these elements must be addressed as vigorously as resources will permit. In the long run, it will be cheaper to launch well-prepared crews in half the time than to hold down the flight rate or risk damaging the Orbiter.

Habitability covers more than just the care and feeding of flight crews. It must also address the efficiency of their efforts on-orbit. Since the adequate support of humans is a minimum requirement, the major gain in crew productivity must be derived from cutting the overhead which is associated with habitability.

2.0 FLIGHT CREW TRAINING

2.1 CREW BACKGROUND

Crew training began informally in the 1972/1973 period when both the CDR (Commander) and the PLT (Pilot) were assigned to work on STS development. Formal training began with the assignment as backup crew for STS-2. In the time prior to beginning formal training, this crew flew every engineering simulation and participated in the STS detailed development. Assignment as the STS-2 backup crew provided 6 months of intensive training focused almost exclusively on mastering the basics of ascent, entry, and systems management. Following STS-2, this crew became the backup crew for STS-3. During this period, attention was focused on the STS-3 mission profile and its rather complex payload. The STS-4 dedicated time was approximately 3 months and this time was split rather evenly between learning the STS-4 mission and exercising basic skill-proficiency training. This schedule resulted in a work pace of about 100 hours/week for STS-2 and about 80 hours/ week for STS-4. It is interesting to note that the formally logged training time reflects approximately 25 hours/ week for STS-2, yet it often exceeded 30 hours/week on STS-4.

2.2 STS-4 SCHEDULE

The STS-4 training was scheduled for 6 days/week until the final 2 weeks when it was reduced to 5 days. Most STA (Shuttle Training Aircraft) training was accomplished on weekends to allow the most effective interaction between the crew and others at JSC (Johnson Space Center). Integrated simulations were limited to 6 weeks due to MCC (Mission Control Center) upgrading activity. The relatively short integrated simulation period caused the crew and flight directors to reduce the number of simulations to allow what the crew believed was the absolute minimum of stand-alone proficiency training in the SMS. The number of integrated simulations supported by the STS-4 crew was substantially less than the flight control team believed was needed to maintain their team skill level. Therefore, other crews were used on simulations that were primarily aimed at systems training. This split seemed to work adequately. In spite of all efforts to simplify the STS-4 training flow, several areas such as contingency EVA (extravehicular activity) were not even given a refresher.

The STA is one of the most critical pieces of training equipment and must continue to be flown on a weekly basis during the final months of flight preparation. The travel time to El Paso and the rigidity of the range schedules means that a single flight requires a full day of the pilot's schedule. The only way this time commitment could be absorbed was to fly on weekends. Even though this results in a higher cost than flying during the week, it is the only way to work it all in until the SMS (Shuttle Mission Simulator) can be made available on weekends. The bottom line is, training for a mission requires 6 days a week.

The total number of training hours was very impressive. The STS-4 crew had over 700 hours in the SMS and had averaged over 900 appproaches in the STA.

2.3 TRAINING PERSPECTIVE

Following the STS-2 mission, the STS-4 crew prepared a note which described their experiences as the STS-2 backup crew. These observations were intended to apply to a new crew's introduction to the STS and are still considered valid. In fact, several of these observations justify restatement in light of the STS-3 and 4 experiences.

Formal documentation of the procedures rationale needs to be expanded. As the flight rate increases, each crewmember will not have the opportunity to be individually coached on the when, why, and how of these rather extensive and mature FDF (flight data file) elements.

The formal training process stresses systems management rather than flying the vehicle. As the newer pilots move into the flight schedule, more formal attention must be focused on pilot technique and skill areas. The older pilots have amassed a huge storehouse of valuable do's and don'ts through their participation in Orbiter development and the OFT/ALT (approach and landing test) preparations. Somehow, these lessons need to be captured and passed on before they are relearned in an embarrassing manner.

What the student is expected to know or do must be the goal of any training program. Nevertheless, such a statement cannot be clearly identified for STS crews. As a result, a considerable amount of the CDR's time was occupied in defining training goals and mapping out a plan of study. Certainly the mission CDR should have a voice in this process, but it should not be his task to develop a plan at the same time he is trying to execute it. This condition was unavoidable in the early STS development, but the time has come to develope a core training program. These program goals should be phrased in terms of skill and proficiency levels rather than numbers of hours or lessons.

The biggest training problem is the sheer volume of material to be mastered and retained. Most of the training time is devoted to off-nominal procedures for a variety of reasons. The STS-4 crew estimates that 75 percent of their time was devoted to training for things they did not do and probably 50 percent of the planned CAP (crew activity plan) was never practiced. This statement is not a criticism, but merely an observation. Early in the STS-4 period, the crew addressed the question of whether or not they should really be practicing the multiple failure scenarios? The premise being that the vehicle design is such that the first failure of a component is almost always transparent and in many cases, the second-like failure is also benign. The problems which are most difficult to handle are those which involve electrical power or data/instrumentation paths in concert with a component failure. If one can assume launching with a full-up vehicle, then there is some justificaion for reducing the training on multiple failures. However, if the launch criteria permits a less than full-up vehicle, then the flight crew's first in-flight anomaly will probably be of the multiple failure variety. Recognizing that an on-time launch was a primary objective of STS-4, the crew elected to continue emphasizing multiple failures. This situation need not always appear to be insurmountable if we can rationally do two things. First, we need to clearly identify what capabilities in which we expect a crew to be proficient. Second, the impact of a launch delay due to component replacement should be compared with the impact of training every crew to cope with multiple failures. There is bound to be some economical compromise. The number of procedures contained in the FDF is large because many have been optimized for each flight phase. Just having a documented procedure does not generally provide a real-time capability. It takes crew training time to both master and maintain an adequate level of proficiency. It is the STS-4 crew opinion that most of these mission-phase-dependent procedures could be consolidated into single procedures which are safe, but non-optimal. This could substantially reduce the training time while increasing confidence in the crew's ability to properly execute the remaining activities. Until the number of FDF procedures is reduced, crew training time cannot be substantially reduced.

The large number of hardware and software work-around procedures incurs a substantial training commitment. While each of these techniques appear reasonable by themselves, the aggregate is impressive. Correcting these vehicle design characteristics is necessary to substantially reduce the training time.

During STS-4 training, each open question was documented using a computer print out. These questions and their answers are available in a notebook. If subsequent crews follow this practice, it should be possible to compare these questions after a few flights. Common questions might indicate deficiencies in the knowledge part of the training documentation.

2.4 SPECIFIC TRAINING OBSERVATIONS

The integrated simulation scripts emphasize the MCC team training and the air/ground interactions. The amount of training that is scheduled for stand-alone operations quickly exceeds the time available. It appears that many of the stand-alone objectives could be included in the integrated plan with proper coordination between the crew, simulation supervisor, and the training team lead.

The long simulation was one of the most productive parts of STS-4 training, even after doing one on STS-3. This should always be accomplished because it provides the best simulation of actual on-orbit workloads.

There is a strong need for a GN and C part-task trainer to avoid the inefficient use of the SMS in this mode.

IFM (inflight maintenance) training is well done, but requires a refresher exercise near the launch date. Crews should have an opportunity to look under the floorboards and behind panels in a real Orbiter as a formal part of training. The video tapes look like a step in the right direction, however, some of the current scenes should be replaced with video of an actual component changeout as soon as an opportunity arises.

Familiarity with the terminal count procedures was provided by crew participation in an abbreviated CDDT (countdown demonstration test). This experience was both adequate and invaluable. Each crew should go through the ingress/cabin closeout procedures and the terminal count timeline. From the crew's point of view, this experience does not require a full system CDDT, however, they need to see the displays and hear the normal calls in the proper sequence even if this is done at a faster than normal pace. It is extremely important to have some experience with the launch director and his team prior to launch day. From the crew's viewpoint, participation in CDDT is the most efficient way to become familiar with both the launch team and the prelaunch protocol. It should be continued as long as possible, perhaps in conjunction with the pad egress training. If CDDT is ever eliminated, then an alternate means must be developed to provide this training.

There are several failures which can occur during the terminal count and require crew/LCC (Launch Control Center) voice communications. Neither integrated nor stand-alone crew training exercise failures which involve LCC/crew coordination because MCC is not in control at this point. Nevertheless, the crew response and habit patterns must be crisp and correct. Appropriate crew responses can only be achieved through practice in the time critical prelaunch phases just as is done after lift-off. Critical malfunctions prior to launch in both stand-alone and integrated simulations should be added to the training program.

The STS-4 crew noted significant reach and visibility differences between the SMS and Columbia. These geometry differences are apparently very subtle, yet critical and may never be completely rectified in the SMS. Launch procedures are generally time critical and are exercised often in the SMS. During integrated simulations, both the flight and ground teams develop an assessment of which procedures can be accomplished, and when and how long it should take. Flight-day decisions are based on these experiences and, therefore, they must be accurate. CDDT should be used to enable the STS-5 crew to verify their personal reach and visibility envelopes. In parallel, a special effort should be initiated to precisely configure the operational seat/panel geometry in the SMS to duplicate OV-099.

The fixed-base SMS does not allow positioning the CDR and PLT seats into the launch position. A great deal of our integrated ascent/abort simulations were conducted in that simulator. Without the ability to properly position the seats, inappropriate habits can be developed. Schedule constraints have, so far, prevented an effort to conduct all launch training in the moving base SMS. When operational seats are incorporated in the fixed base SMS, they should be capable of being positioned in the launch configuration.

Stand-alone training for ascent requires that the SMS be provided with an ARD (abort region determinator) type capability. Today, this training is accomplished by using the full MCC team. In the future, the MCC teams will not have the time to individually train each flight crew to the desired level of proficiency.

The SMS should be capable of driving all window scenes simultaneously to allow better on-orbit timeline training.

The fixed-base SMS should have a high-fidelity middeck to enhance on-orbit training with full stowage.

Full stowage of the SMS for integrated timeline simulations is essential to avoid embarrassment when on-orbit. Today, much of this equipment must be borrowed from other facilities. The logistics of this activity are so cumbersome as to restrict its application to the long-duration simulation. At the earliest time, JSC should acquire a dedicated set of SMS stowage hardware for routine use.

After the OMS-1 (orbital maneuvering system) maneuver, the main engine slew to the stow position is a very dynamic operation which induces a significant series of RCS (reaction control subsystem) firings. The SMS should model the dynamics of the SSME (Space Shuttle Main Engine) stowage, not just shake the motion-base cabin.

The SMS needs a capability to uplink a state vector and refinement during stand-alone training. Training which involves navigation errors or IMU (Inertial Measurement Unit) recovery now must be done during integrated sessions to have this capability.

The number of SMS reset points is inadequate for efficient training. To practice entries on other than the preflight planned revolution requires starting at a canned point, stepping ahead to the deorbit maneuver and then flying the entry. This same procedure must be used in practicing approaches to the alternate landing sites. Further aggravating the situation is the difficulty in saving and using safe stores. Safe stores cut on one base cannot be used on the other base and they can be overwritten, with each new training load wiping the previous one out. One of the more critical timelines is the period surrounding the OMS-1 maneuver, yet the only practical way to now simulate this critical area is to fly an entire ascent. Selection of reset points should consider stand-alone training requirements as well as those needed for integrated simulations.

The STA is an invaluable training device, yet its efficiency could be dramatically enhanced if it had the capability to record video of each approach and play it back between approaches.

STA should be provided with a density model such that sea-level performance can be simulated at the Northrup strip at White Sands.

STA practice to unsupported runways should be encouraged throughout the formal mission training period to aid the pilots in developing techniques for use in TAL aborts. Since these techniques may be quite different from those normally used, they should not be the last ones practiced.

The use of the KC-135 as a landing trainer should be continued. Its primary virtue is that it is the only opportunity the crewmember has to actually land an aircraft of a size and geometry similar to the Orbiter. The difference in mental approach between a simulated landing in the STA and an actual landing with a real aircraft on a runway is significant. As a bonus, the KC-135 requires a considerable amount of pilot concentration during landing just as the Orbiter does, albeit for different reasons.

3.0 FLIGHT DATA FILE (FDF) AND MISSION PLANNING/EXECUTION

The manner in which operations are conducted and the material used to support these philosophies are really one topic. In fact, it is very difficult to separate vehicle design and training, but this has been attempted as an aid to organization in this report.

3.1 STS-4 MAJOR CHANGES

STS-4 was the first mission to make a conscious effort to use the Astronaut Office organization as the interface between the FDF community and the flight crew. As far as the STS-4 crew could tell, this procedure worked very well.

At the beginning of the STS-4 preparation period, three major FDF changes were agreed to as objectives within the Flight Operations Directorate. These were the use of cue cards rather than the PCL (pocket checklist) during entry and the streamlining of the PDP (post-insertion deorbit preparation) checklists.

3.2 CUE CARDS

The initial attempt to use cue cards rather than the entry PCL during MM (major mode) 304/305 was accomplished quickly. Since we had previously agreed that the ascent cue cards should cover any ascent evolution including RTLS (return to launch site) and TAL, it became apparent that entry ought to be a subset of the ascent procedures. The new objective became one of developing a single set of cue cards which covered all major mode 102, 103, 601, 602, 603, 304, and 305 systems anomalies. This task did not turn out to be as straight forward as expected because of the optimization which had been built into each existing set of procedures. Many of the changes, which on the surface appeared to relate solely to format, turned out to actually change the technical content. A related problem was the amount of data which was appropriate. For example, if an IMU fan fails, is a written procedure required to tell the crew to switch to an alternate fan? The flight crew believed this was unnecessary; however, the systems people countered with the opinion that obvious as this action appeared, it was necessary to document it. The real problem turned out to be that the onboard FDF is the only source for those procedures.

The process of developing new cue cards, verifying their technical content and producing a training product took much longer than anyone would have expected. The training products were further delayed because of the need to prepare the flight units. This resulted in the crew seeing flight-like units for the first time during the last two weeks of training.

The following recommendations are suggested for consideration on future flights.

a. Develop a detailed procedures document that describes the what, when, and why for ascent and entry systems anomaly responses. The cue cards should then contain only those steps that are not obvious to a trained crew.

b. Critically examine the need for unique ascent and entry responses to a common symptom. It is the STS-4 crew opinion that a common response that is safe is preferable to two optimal responses. Reducing the number of procedures in ascent and entry will not only shorten training time, but will also improve the probability of an accurate response when required.

c. Avoid nice-to-do improvements within 3 months of a mission. This does not mean stop improvements, but rather recommends separating the flight production and development functions. A group of knowledgeable people ought to be able to work out improvements and hand over a verified set to the crew in training.

d. The three existing pocket checklists should be combined into one.

3.3 POST-INSERTION DEORBIT PREPARATION

3.3.1 Post-Insertion

The STS-4 crew developed a post-insertion procedure which used picture panels to establish the on-orbit switch configuration. This technique has the virtue of allowing the crewmember to approach any panel in any orientation and still achieve the proper configuration. In addition, the picture procedure is much faster and less error prone than the individual switch callouts used previously. The only problem encountered during STS-4 was that the panel drawings were not ordered in the FDF in the same sequence in which the cabin was configured. The entire post-insertion routine was typically executed in 2 hours in the SMS, but required approximately 3 hours in flight. Most of the extra time was invested in doffing the suit and transferring articles from the pockets of one to the other.

To expedite the initial unstowage, a list of early-use items was carried on the crew kneeboard. These items were those required prior to the first meal period. The intent was to get far enough ahead of the timeline to allow full on-orbit stowage reconfiguration prior to entering the CAP at an elapsed time of 4 hours. This latter activity was not completed until the first night's sleep period because of minor timeline interruptions and the zero-g environment.

The following further improvements are recommended.

a. Publish the picture switch lists in the order they will be used.

b. Schedule a period to deploy the spacecraft stowage to the orbit configuration in the time saved by not having to doff the EES (emergency escape suit).

3.3.2 Deorbit

The deorbit preparation activities were substantially streamlined for STS-4. This was accomplished to both shorten the time from wakeup on flight day 8 to the deorbit firing and to provide time for a thoughtful crew briefing prior to the firing and entry. The new procedures took approximately 2 hours in simulation, 2½ hours on-orbit and were scheduled for 4 hours. The reason it took longer inflight was because it took longer than anticipated to don the suit. These procedures worked flawlessly and provided enough time to accommodate some unanticipated events, and this is exactly how entry day should always be. Any extra time might be spent getting one last treadmill exercise.

3.3.3 Checklist (Ascent, entry/orbit)

The STS-4 plan attempted to remove all mission dependent data from the ascent and entry checklists. Even though changes in mission software may require some detail changes, the concept of using timeline and targeting cue cards seemed to accomplish this goal without increasing the crew workload. In fact, the timeline cue cards which provided a summary timeline from lift-off through the post-insertion PDP and again during the deorbit PDP were a significant aid to the STS-4 crew.

The current ascent checklist flows smoothly and is set at a slow enough pace to allow doing things deliberately, while the crew transitions to the weightless environment.

The ascent checklist calls out transfer to internal power as part of the terminal count yet this has been gradually occurring over enough time that is is totally transparent to the crew. On the other hand, the SSME slew to the start position can be felt, occurs at a specific time and is not mentioned in the procedures. The terminal count is a period where it is important for the crew to recognize what is normal and what is abnormal. Checklist and training should emphasize only those things which are visible to the crew or require crew response to avoid real-time confusion. The power transfer call in the ascent checklist should be deleted and the engine slew cues added to the motion base SMS.

The orbit operations checklist now contains the procedures for the FCS checkout. It was moved from entry day to accommodate any discovered anomalies and to relax the entry preparation timeline as much as possible. Since the crew can handle, during entry, any of the problems which might be identified by the FCS checkout, it raises a question as to the importance of this procedure. At some point in the operations era, it may make sense to delete this as a routine procedure, but retain it as a diagnostic tool to be used when required. If this procedure is executed it should always be done with the PLT and CDR procedural steps in parallel rather than in sequence.

3.4 OTHER FDF ARTICLES

The malfunction procedures, reference checklist, and the OMS/RCS slide rule appear to be good candidates for eventual inclusion in mass memory.

The reference checklist contains an alphabetical stowage list. Unfortunately, not all equipment can be found using its common name. For example, the STS-4 crew wanted to find the spare urine filter, but could not find it in the list. As these problems surface, the nomenclature should be updated.

During training as well as inflight, the yellow plastic caps were used to indicate switches that were not functioning normally. In training, the crew found that the best way to remind themselves of anomalous switch functions was to apply switch caps and tape to non-functional switch positions. The SMS had some yellow electrical tape as well as the yellow plastic switch caps. The loss of some data or power busses can lead to one or more switch positions being non-functional. Rather than change every possible procedure to reflect these non-functional positions, the STS-4 crew found it was easier to mark the panels as reminders. It is recommended that some yellow tape be added to the FDF kit to allow use of both tape and switch caps as panel reminders.

The afternoon of day 7 was scheduled for pre-entry stowage. A copy of the stowage list had been annotated to indicate what was to be left out until entry morning. The process of stowage was to have one crewmember open each locker and call out the items to be stowed. The other crewmember retrieved the necessary equipment and passed it to the stowing crewmember. This worked very well and allowed a very efficient operation. Two hours were used in this activity. The rest of the time was used in taking pictures missed earlier in the flight. Stowage was simplified by starting a "return to Houston" bag on day 1. This was the large jettison bag flown for the first time on STS-4. The intent was to put all annotated FDF articles, film, and VTR and tape cassettes into one bag for easy location after landing. Unbeknownst to the flight crew, the post-landing procedures required that this bag be inventoried and only those items designated were immediately returned to Houston.

The postflight procedures should be changed to insure everything in the "return to Houston" bag is indeed returned, whether it is on the manifest or not.

3.5 CAP AND ORBIT TIMELINES

The pace of day 1 had been intentionally relaxed to allow for the anticipated zero g crew learning curve. The day was scheduled to end at 9 hours MET (mission elapsed time), yet the activities were not completed until several hours later. Since the crew had been on schedule at the end of OMS 4 maneuver, they were surprised at the rate at which they fell behind the timeline. Postflight analysis of this day shows that activation of the Getaway Special, scheduled for 10 minutes (a 2-minute job) took approximately 1 hour because of a malfunction. The COAS calibration took 20 minutes as opposed to the scheduled 5. These delays, when added to the deferred spacecraft stowage, account for most of the time discrepancies, but illustrate the sensitivity of timelines to unanticipated events. The crew elected to delay the sleep period and insure that day 2 would start properly. In retrospect, this seems like an appropriate decision, however, had the first day been a longer one, it might not have worked as well.

The crew's zero g learning curve appeared very steep during day 2. By the end of day 2, crew efficiency had approached a level of steady-state proficiency. It should be noted that this is in no way related to motion sickness.

During STS-4, the flight crew felt that they were working as hard as they ever had throughout the mission from the end of OMS maneuver 2 to the afternoon of day 7. The onboard perception was that of scrambling every minute to stay caught up. This apparently did not come across to the MCC team since they were surprised by this crew comment during debriefing.

Sixteen hours of reacting to timelined activity is very fatiguing. Breaks for meals and exercise are very necessary and should be honored as often as possible. If one activity is running over its allotted time, it should not be terminated prematurely, but when it is complete the time off should be reinstated.

The PLT got his first exercise period on the treadmill on day 3. The CDR got his first on day 4. Both exercised each subsequent day through day 7. About 1 hour per crewman is required to accomplish 20 minutes of exercise. This is certainly time well spent.

Changes to the mission thermal attitude sequences resulted in massive rescheduling of flight activities beginning with day 4.

The changes were sent up via teleprinter message just before wakeup on day 4. Typically, the CAP allocated 15 minutes each morning for teleprinter review. Simulations had shown that this time is about right for a nominal day's update. Flight experience validates this assumption. However, with a massive update this is not adequate using our current CAP format. On day 4, the crew never had time to develop a mental overview of what was going to happen that day. Consequently, this was probably the hardest day of the flight. The crew was no longer in a position to contribute to the day's activity because they were just hanging on, reading each new activity as they got to it. This condition was remedied on subsequent days by a major ground effort. The subsequent days were completely replanned rather than trying to modify the existing CAP. These brand new CAP's were sent up in two forms each day. A summary of the day's activity was prepared in chronological order to show the crew what would be done that day. Then a detailed execution message was sent. This worked very well, in spite of the fact that day 5, 6, and 7 were totally new, as long as the summary was received first. The crew mounted the summary on the forward glare shield and used it to plan and execute the day. The details were clipped using the now useless CAP, as a clipboard. Other supporting messages on systems status were clipped together and velcroed to the side of the PLT's ejection seat. This file was used in a fashion analogous to a NOTAM file. This mission used more than 200 ft of teleprinter paper.

Before flight, both the flight crew and the MCC team must agree on how and when mission replanning will be accomplished. The STS-4 crew had discussed this extensively with the planning-shift Flight Director and the exchange of ideas made it possible to just barely cope with the revised CAP. One of the difficulties for both flight and ground teams was the relatively rigid format of the CAP. If the CAP is going to contain all the actions in detail, then the CAP must be executed as planned to avoid making costly mistakes. Flipping back and forth within the CAP is inherently inaccurate and time consuming. It defies ingenuity to keep track of what has been done or what is coming next. The other extreme approach is to package the details in a CAP supplement and use the CAP only as a master schedule. This makes execution of the CAP less efficient on a nominal day, but allows a great deal more flexibility.

In any situation which requires operating off a teleprinter message, the crew will need something to lay it on so that they can write notes and check off completed steps. A clipboard might be useful.

The flight crew spends a great deal of their training time mastering the anticipated flight timeline. This is appropriate for their role as supervisors and executors of the CAP. They cannot execute these responsibilities if they do not know what is coming next or where they are headed. Therefore, the following suggestions are offered:

a. Decide preflight what, when, and how replanning of the CAP will be accomplished. Different missions may require different strategies.

b. When massive CAP changes cannot be avoided, a new day's summary must be generated and shipped first. Details should be avoided, but can be sent up later.

c. Avoid forcing the crew to operate in the response mode. If it becomes necessary for short periods, then a master plan should be discussed as soon as possible. It is the only way to avoid costly mistakes.

d. Provisions for handling and writing on the teleprinter messages should be provided.

e. When major CAP changes are required, a commensurate period must be scheduled in the new CAP to allow the crew to digest the content.

f. During the STS-4 long-duration simulation, the MCC team discovered that if they listened to the playback of the crew intercom, they could discern what the crew was thinking about the next day. This allowed them to avoid telling the crew things the crew already knew and allowed them to address crew questions. This procedure was formalized for the STS-4 mission. The plan was for the crew to record, on the ICOM, a summary of the day's activity, express questions and opinions about the next day's plans and feedback their impressions of what the MCC had told them during the day. This worked with varying degrees of success during the mission. The primary problem was missing the summary section of the tape dump because of an inadequate set of markers for the crew to identify this time to the MCC. The MCC had wanted this summary before or during the pre-sleep period. The crew, however, never got to it until communications had been secured for the evening.

This concept should be considered for subsequent missions after developing an unambiguous set of air-to-ground cues to indicate the required times.

Flight crews are frequently approached on the side about doing a little extra to collect some additional data. This seems innocuous enough and the flight crew is always willing to do a little extra to help. This process, however, runs the very real danger of allowing the mission priorities to be subtly reshaped without everyone being aware of that fact. Except for things the flight crew pursues in their "free time" (as opposed to meal and sleep periods) these activities should all be formalized at least to the extent of appearing on an official shopping list. The use of an official shopping list was successful on STS-4 and substantially improved the quality and quantity of returned data.

Wake up on day 8 was delayed over an hour because the landing revolution had been moved from the first to the second opportunity. This was appreciated by the crew, however, one of the major problems tackled in the development of the CAP had been how to move the sleep periods forward during the mission. A greater than 6-hour sleep adjustment was cut to approximately 4 hours by shortening day 1 and day 8 activities. Nevertheless, it might have been more effective to not have moved the sleep periods at the beginning of the mission quite so much, rather than pull them forward on the high workload days and then give some of it back at the end.

Circadian rhythms can be changed, but this must be done with a great deal of thought and planning. While sleep periods can be scheduled at any time, many crewmembers will find it difficult to turn in early. The end result is a lack of productive sleep.

The amount of sleep-period adjustment required on-orbit should be minimized by tailoring the launch and deorbit day activities as much as possible.

The relaxed pace at the end of day 7 provided the first real opportunity for the flight crew to observe and ask questions about the earth passing by outside. During this period, it was noted that massive lightning discharges were taking place over desert areas. It was also noted that those same areas had experienced a very noticable build-up of aerosol, assumed to be dust, during the mission. Apparently related, but not continuous discharges were observed to spread over a distance estimated to extend as much as several hundred miles. These observations seemed to correlate with an earlier observation that the colors and intensity of the atmosphere at sunrise and sunset varied with both latitude and longitude.

Flying curious, intelligent and trained observers in space will most likely lead to many new endeavors if time can be provided for them to use their natural skills in an unprogrammed way. Many of the current astronaut population have advanced degrees in various fields where their backgrounds may find application. Each crewmember should be scheduled for some number of hours for individual pursuits during each mission.

4.0 VEHICLE SYSTEMS OBSERVATIONS

Vehicle systems have apparently achieved a remarkable level of maturity during the initial four flights. Most of the STS-4 observations can be catagorized as constituting an operational suitability evaluation rather than as a functional assessment. Even though a change to the hardware or software requires an investment of resources, it is the opinion of the STS-4 crew that the potential cost savings to be realized through reduction in crew training requirements or increased orbital crew efficiency warrants a thoughtful review.

4.1 OBSERVED BASIC ORBITER SYSTEMS CHARACTERISTICS

4.1.1 Nuisance Alarms

Three types of nuisance alarms occurred during dynamic flight. They were:

a. The dp/dt alarm occurred as anticipated; however, unlike the SMS, the CDR was unable to see the dp/dt gage. The limits on this alarm should be adjusted to avoid nuisance alarms during ascent.

b. In spite of adjusting the evaporator outlet temperature alarm to its upper limit, the alarm was still triggered near SRB (solid rocket booster) staging. This nuisance alarm has occurred on three of the four launches and has two potential crew traps. First, a valid alarm may go unrecognized and second, the fact that the sensor is saturated complicates any ensuing corrective action during powered flight. The crew response time to activation of the evaporator can alter the incidence of this occurrence. This is an unfortunate aspect of our current design since this function was intended to be under GPC (general purpose computer) control, yet because of a potential single point failure, we are procedurally doing this at SRB staging. The transducer limits should be expanded to avoid these nuisance alarms and to aid in subsequent corrective actions following a real malfunction. If the sensor range cannot be extended, then another way to avoid this nuisance alarm should be developed.

Ascent is sufficiently dynamic that normal functions like enabling the evaporator should be automated. The CDR should devote his undivided attention to monitoring the ascent trajectory. The system should allow the evaporator and NH_3 to be launched in the GPC position.

c. Two nuisance master alarms were encountered during entry. The first came when the SSME (Shace Shuttle Main Engine) TVC (thrust vector controller) was repressurized just prior to entry interface and the second occurred at the major mode 304 transition when the elevons were commanded to move to the entry position.

The problem in these cases is that there is no filter or time delay in the primary hardware caution and warning system for low hydraulic pressure. The backup caution and warning software avoids this condition with a filter. A time delay should be added to the primary caution and warning hardware for hydraulic pressure.

4.1.2 Vehicle Torques

Unexplained torqueing of the vehicle was noted during the COAS (crew-optical alignment sight) calibration and during a gravity-gradient test period. This torqueing was large enough that the CDR was required to use an excessive number of vernier RCS pulses to keep the COAS calibration star in a useful location. This torqueing also caused the gravity-gradient attitude to diverge dramatically in roll within 1 hour. The source of this torqueing was not identified in flight and was either absent or greatly diminished by day 2 since gravity gradient held for the entire scheduled period. It has been postulated that this torque was created by water in the TPS being vaporized. A similar, although less obvious, condition may have occurred during the STS-2 gravity-gradient exercise. Prior to launch, STS-4 experienced a very heavy rain and water entrainment was considered likely. Depending on the quantity of water trapped, it is possible that some of the STS-4 ascent performance loss might be attributed to the water.

The source of this unanticipated torqueing needs to be identified. If water trapped in the tiles remains a likely candidate, it may be possible to measure the mass with a series of RCS (reaction control system) firings spread over the mission. If water in the tile is indeed a repeatable phenomenon, then a method to prevent or limit the amount of water seems appropriate. The effects of hydration on silica structural integrity should also be verified.

4.1.3 Payload Bay Doors

Day 4 included a thermal gradient PLBD closure test. The port door appeared to close normally, however, when the aft bulkhead latches were commanded closed, the door deflected substantially at the aft bulkhead and the latches jammed after only partial travel. The aft PLB (payload bay) television cameras were used to send pictures to MCC for evaluation. The PLB lighting was degraded and the latch mechanisms were all dark, offering very poor contrast. The crew had considerable difficulty identifying major components and in positioning the television cameras.

It is imperative that the cause of this door interference be determined so that adequate operational tolerances can be provided. A simple technique should be developed to allow the flight crew to insure a safe latching, if possible, if all conceivable tolerances cannot be demonstrated to be adequate.

Increased crew training in the area of PLBD mechanisms, as viewed through the television, should be considered until the acceptable PLBD operating envelope is defined.

4.1.4 Extravehicluar Mobility Unit Communications

When the EMU (extravehicular mobility unit) communications was activated, the PLT on the flight deck could hear the extravehicular crewmember normally, but the extravehicular crewmember had so much noise that it was hard to understand the cockpit. This noise did not prevent voice, but was bad enough to make extravehicular activity questionable. During the EMU activities, the noise suddenly went away and good communications existed even though the crew was not aware of what caused the improvement. The cause of this condition should be determined prior to scheduled EVA operations.

4.1.5 Entry Dynamics

During entry, both crewmembers were surprised by a vibration which was described as feeling like atmospheric turbulence in a high-speed, high-wing loading aircraft. These sensations began around Mach 22 and varied in intensity throughout entry until the transonic buffet became the dominant vibration. This had not been previously reported and raised some question about the wisdom of executing the PTI (programmed test input) protocol. Just prior to the Mach 18 PTI, these vibrations reached a peak and then started to diminish enough that the PTI was executed without concern.

Postflight data evaluation from surface accelerometers suggests that these vibrations were probably the result of the yaw RCS exciting the vertical fin. The structural model infers that the accelerations of the cockpit resulting from the fin motion should have been on the order of $\pm 0.02g$. It is a little surprising that such a low level would have been so obvious. If the vibrations experienced were solely the result of structural bending, then it seems prudent to evaluate the inherent structural damping to insure that adequate margins exist at higher q, especially in the presence of flight control system/sensor anomalies.

4.1.6 Brake Performance

Prior to flight, the brake and wheel/tire performance received a lot of attention. The braking DTO (detailed test objective) called for application of brakes at a ground speed of 140 knots and a constant deceleration level of 8 to 10 ft/sec^2. The crew was advised that this level would not result in activation of the antiskid system until the velocity was relatively low when the deceleration levels would naturally be reduced. During SMS training, the STS-4 crew found it very difficult to achieve a constant deceleration rate. However, with a lot of practice, the CDR learned how to hold roughly 10 ± 1 ft/sec^2. During the actual landing, the CDR was unsuccessful in raising the deceleration level to his target of 10 ft/sec^2. The maximum value was 9 ft/sec^2 and this was only for a brief interval. The CDR was also frustrated by his inability to hold the deceleration levels anywhere near constant. Both crewmembers had the distinct impression that the antiskid system cycled several times at the beginning of brake application.

Postflight discussions and data analysis indicate that the antiskid system did not activate and that the brake pressure fluctuations followed the brake pedal commands normally. One problem with this evaluation is the fact that the brake pedal position is sampled much less frequently than the rest of the data so that the exact cause and effect relationships are difficult to quantify. The fact that the day 8 deceleration levels fluctuated as badly as they do in simulations raises a question about the brake pedal pressure gradient and magnitude. It is not obvious to the crew whether these force levels are too high, too low, or if there is some other reason for the non-uniformity of the brake commands. It is the opinion of the CDR that the manual task of precisely controlling Orbiter deceleration rates is an unreasonable one. If precise levels are required to insure stopping or to preserve the brake life, then an automatic deceleration system should be developed. This system is currently available in some commercial transports. In an ideal design, the pilot should be able to select the desired deceleration level and then command execution with a single switch. Differential braking should still be accommodated and the deceleration level should be capable of adjustment during automatic braking. The cost of replacing the brakes following heavyweight landings can become significant over the life of the STS. Most probably, the vehicle landing and abort weights will rise as we develop the launch systems and techniques. This will severely complicate an already marginal situation. Early in the Orbiter development cycle, the design included a drag chute which was eliminated because of its complexity, weight and a belief that the Orbiter aerodynamic drag was sufficient to stop comfortably on a 10,000 ft runway. Since then, our operational capabilities have increased to the point where alternative deceleration techniques warrant further consideration. Since the Orbiter already has a substantial thrust structure, it may not require a great deal of additional weight to provide a tail hook which could be used for nominal landings and at planned abort sites. The brakes should be retained as emergency devices to cover contingency landings or hook failures. This would essentially remove brake refurbishment costs from the operational employment of the STS.

4.2 BASIC ORBITER SYSTEMS IMPROVEMENTS

4.2.1 Ascent Displays

About 1 minute into ascent, the crew noticed that the trajectory appeared to be depressed on the BFS (backup flight system) trajectory 1 display. The ADI (attitude direction indicator) attitude error needles also indicated a slightly low attitude (nose towards the earth). Once the displays moded to OPS (operations) 103, the crew confirmed that the trajectory was still slightly depressed and the propellant remaining calculation indicated approximately 1 percent less than normal. The MCC confirmed the crew's assessment of low performance and indicated that the abort boundary calls would be slightly later than normal. The trajectory was still slightly low at a velocity of 16,000 ft/sec, but the propellant was normal.

The STS-4 crew used the BFS ascent trajecory displays because they provide more useful information than the PASS (primary avionics software system) display. The only data used on the PASS display was the calculation of propellant remaining and the display of TMECO (time to main engine cutoff). TMECO was compared with the same value in the BFS to assure the crew that the BFS data were valid. Based on extensive training, the crew had developed a good feel for how much performance could be degraded while still making a viable MECO target. This allowed the crew to get a head start on planning their post-MECO activity. There is not too much time between MECO and the OMS 1 maneuver to make a decision about which targets should be loaded, etc. Even when the MCC calls these target selections, the STS-4 crew found they did a better job if they could anticipate what would probably be required. Today, the BFS ascent trajectory 2 display is the only way the crew has to monitor nominal trajectories or TAL aborts.

The use of the BFS trajectory displays creates another problem since the BFS is also the only source of systems data in OPS 1. To provide both systems and trajectory data from the BFS during ascent, requires that one CRT (cathode ray tube) (1) be assigned to the BFS with the BFS CRT SELECT switch and the second CRT (3) be assigned permanently through the keyboard. This introduces other complications if a GPC (general purpose computer) or CRT fails.

The BFS does not display the propellant remaining in OPS 103 so these data have to be obtained from the PASS trajectory display. To interpret these data, the CDR must refer to a nominal profile which is on a cue card mounted by the ADI. This is a time consuming cross check and requires a profile which is derived from the flight I-loads as opposed to generic data.

Proper use of both the trajectory profiles and the propellant values can only be accomplished today by practicing with the flight I-loads. The software should eventually be upgraded to include a propellant remaining versus velocity profile. This should be displayed along with the current calculation or perhaps only the difference needs to be displayed.

4.2.2 Abort Data

During preparation for STS-4, a scheme was developed to allow the crew to determine when an RTLS (return to launch site) powered pitch-around should be initiated. Unfortunately, this scheme required a SPEC 0 memory read after abort initiation which is tedious and error prone. This strategy, however, eliminated the ambiguity over whether the guidance was converged and when/if manual intervention was required. (The use of a memory read during an abort is totally unacceptable.) If a piece of data is required in an abort, it should be automatically displayed.

Several pieces of critical abort data are currently not displayed to the flight crew even though the information is resident within the GPC. The crew should know the time of main engine failure, the status of the guidance-converged flag and the mass target for RTLS-powered pitch-around.

4.2.3 External Tank Separation

A primary concern in the execution of RTLS aborts is the need to separate the ET (external tank) with less than 2 percent propellant remaining. In fact, the entire RTLS strategy has to be built around a very critical fuel dissipation phase. This is the only area of the RTLS-powered flight-guidance scheme to uncover problems. There is some evidence that safe aerodynamic tank/Orbiter separation can be attained with substantially larger propellant loadings. The full envelope of safe aerodynamic ET separations should be defined and the RTLS guidance revised to capitalize on it.

4.2.4 OMS Burn Logic

One of the most time consuming preflight crew activities is attempting to learn the OMS/RCS firing logic during ascent. Today, a relatively large number of unique emergency procedures exists and very little real-time insight into what is actually happening during each procedure exists. The STS-4 crew is not sure if all of these procedures can always be executed due to changing reach and visibility envelopes during ascent.

Training time must be reduced in the operational era and this area represents a potentially large reduction if the hardware and software could be made compatible with operational procedures. Certainly the OMS no. 1 (MM104) maneuver logic should be made consistent with all other OMS maneuvers.

4.2.5 OMS Gaging

The OMS gaging system is complex and has not been reliable, yet crew knowledge of the amount of propellant remaining is essential.

Accurate propellant gaging in zero g has always been difficult. In Apollo, the crews relied on accumulated firing time for the service propulsion system rather than the gaging. The OMS gaging has proven unreliable and even when it works properly is only accurate after a firing has started. Because of the tank construction, there is an ungageable region which must be estimated in all cases. This estimating is done in the hardware and assumes that only one orbital maneuvering engine is drawing propellant. This assumption is not valid during many firings, especially ascent abort propellant dumps. Since the GPC calculates the amount of OMS propellant used by the RCS on-orbit rather accurately, why not develop a software calculation of OMS propellant quantity to be based on counting the number and mass flow of all users and subtracting this from the initial tank load.

4.2.6 Structural Limits

Columbia has a thermally induced 2g limit beginning near the TAEM interface and extending through rollout. Columbia also has a 6 ft/sec h limit for touchdown, a nose lowering limit and a runway smoothness limit all constrained by the forward fuselage structure. While none of these limits were exceeded on STS-4, they were uppermost in the crew's mind during portions of vehicle recovery. During the entry sweeps, the vehicle c.g. load factor changed by approximately one and yet neither crewmember was aware of this change.

There are a number of reasons why pilots should not be required to remain within these limits with an operational vehicle. The task of maneuvering around the HAC (heading alignment circle) to set up the landing energy is sufficiently demanding that the pilot should not be required to cross check his g level as an additional constraint. The difference between a normal HAC n_z profile and an excessive one is too small to rely on physiologic cues as a warning. The pilot must fly whatever trajectory is required to assure a proper landing set up.

The landing h limits are normally not a problem; however with any slow landing, a balloon or steep approach can easily result in touchdowns at or above the 6 ft/sec limit. The difficulty in achieving smooth landings is caused by the aircraft geometry and can only be controlled by a proper set up. Once a set up has been missed, the pilot has no choice but to do the best he can with the conditions at hand. Any upsets to the trajectory caused by turbulence, wind shear or last-minute energy corrections can create a condition which requires the pilot to use his controls in such a way as to significantly increase the probability of a touchdown h in excess of 6 ft/sec. Sitting as high above the runway as the Orbiter pilot also severely complicates this task.

Controlling the nose derotation is another region where the pilot has very little latitude. Today's techniques work well as long as everything proceeds normally. If the pilot lands slow for any reason, he will have the nose too high and at too low an airspeed to allow for anything less than perfect post-touchdown technique. This is very difficult to achieve or simulate. In this case, the problem is again related to Orbiter geometry; short nose gear (negative α during nose-gear touchdown) and the desire to avoid large up-elevon deflections with the nose on the runway (negative α plus elevon downloads the main gear).

The final problem is beyond pilot technique unless landing speeds can be reduced. These inherent limitations apply equally to pilots and autoland, therefore, the following recommendations are offered for consideration.

a. Apply structural beefup as necessary to provide a 2 1/2g airplane mode n_z limit for all nominal end-of-mission conditions.

b. Improve structural margins to assure that a landing $\dot{h}$ up to 6 ft/sec at all landing weights can be tolerated without concern.

c. For long-term operations, the nose strut should be extended to avoid negative α problems or active canards should be considered. Active canards, although expensive to retrofit have sufficient virtues to justify serious consideration. Active canards would provide a vehicle center of rotation near the c.g., thus making the Orbiter fly and land in a conventional manner. Active canards would also allow the elevons to be lowered as landing flaps. Back of the envelope calculations indicate that a 240,000-pound Orbiter could be landed at close to 150 knots with the elevons deflected to approximately 10-degrees down. It is conceivable that an active canard could even unload or control the nose derotation below zero angle-of-attack and avoid the need for nose-gear extension.

4.2.7 Habitability

The general subject of habitability is extremely important to long-term operations because of its implications for crew health, morale, and efficiency. Individual topics are discussed although the general subject must be treated as a system to reach an effective operational solution.

4.2.8 The Closed Ecological System

The spacecraft becomes a closed ecological system on-orbit and must be treated as such since the components interact. The subjects of interest are the WCS (waste collection system), food preparation, personal hygiene, and trash management. Any change in one can affect the others so the system must be treated as an entity.

4.2.8.1 WCS.- A detailed debriefing of the WCS problems and comments has been given previously, hence, only a brief summary will be given here.

a. The preflight training was excellent and gave the crewmen confidence that body positioning was correct and cemented their knowledge of the WCS operations. This training is strongly recommended for new crewmembers.

b. The human interface with the WCS for fecal collection is not natural. In fact, the OFT-design hindered rather than aided proper body positioning.

c. There is not an adequate restraint system for urine or fecal collection.

d. The slinger speed began to vary and noticeably slowed after day 4 of the flight. Fan/separator motor speed also varied during the last days of the flight.

e. The urine-cup design allows urine to collect under the lip of the cup and in the funnel itself. There is always a cleanup problem with this design. Urine surface tension allows the urine to run around the funnel and plastic cover. Unique male and female urine adapters should be considered.

f. The urine cup spring retainer system came completely apart during an attempt to positions the cup on the track for urine collection; during fecal collection the adjustment limits for this purpose are inadequate. Something akin to a gooseneck-type adjustment came to mind as a possibility.

g. Air flow is inadequate for urine collecion of the "last drop." Possibly a high-flow flush mode could be implemented.

Some of these problems require remedies that must be engineered on the ground. Those problems which have to do with zero-g operation are probably easiest to solve by providing a set of candidate devices for inflight development. A DTO (detailed test objective) should be defined to cover this on-orbit activity and thereby insure adequate flight plan integration.

4.2.8.2 Personal Hygiene.- The following observations are made based on flight experience and projections for larger crew operations.

a. There can be little privacy and certainly no room for modesty when it comes to personal hygiene. Bathing requires access to the water dispenser that is located in the middeck which is a focal point of crew activity. Perhaps a curtain is required.

b. Each crewman was allotted two washcloths and one towel per day. One cloth is wet at the water dispenser and soaped for bathing. The second cloth is used for rinsing. Since there is no way to rinse the cloth, it becomes very soapy. When the galley flies (not on all flights) there are provisions to wring a cloth and re-wet it for rinsing. When shaving, one of the cloths must be used to wipe the razor and to remove shaving cream from the face. You can readily see that the daily washcloth allowance is rapidly depleted. Add to this a spill and subsequent hygiene during the day and the towel supply shortage problem is evident. A permanent towel washer/squeezer like the one used successfully in Skylab should be implemented and the number of towels put on board should be increased until the washer/squeezer is available.

c. Bathing water must be obtained from the same station as drinking water, a potential health hazard. With larger crews, the need to allow concurrent food preparation and hygiene becomes obvious. Isolated hygiene and food water supplies should be developed for the operational Shuttle.

d. The wet wipes provided were all used by early in day 8. The wipes were useful and convenient for cleaning up the WCS, although that was not the intended usage. The quantity of wet wipes should be substantially increased.

e. The "dop" kit design leaves a bit to be desired. All items are installed in the kit under an elastic loop with such tension that removal sometimes causes the kit to release from its velcro-stowage location. Except for the soap dish, when an item is removed from the kit there is no velcro with which to restrain the item and also trying to insert it back under the elastic loop was difficult. For example, removing the shaver from under the loop required so much pressure on the tube that when the cap was removed, shaving cream squirted out. Also, the razor blades were stored under the same loop and became free when the cream was removed. One quickly runs out of hands with a tube of shaving cream and its cap in one hand and a hand full of cream to rub on the face in the other. Velcro restraints for all items in the kit should be provided.

4.2.8.3 Food Preparation.- The operations-type food preparation and eating worked very well.

a. Only one mishap occurred during rehydration of a food package when the water injector needle punctured the side of the septum. The alignment of the needle and package is critical.

b. The operations-type food seemed to require slightly more water than instructed to obtain proper consistency.

c. The squeeze cutoff on the plastic straw was required for some beverages and not for others. Some tended to dribble out without the cutoff.

d. Food with high surface tension (mushroom soup) could not be accelerated permanently into the container bottom by swinging it around. The fluid would crawl into the plastic cover making a rather messy opening.

e. In addition to the operations-type food packages, some food is still provided in "wet packs". During STS-4, the crew found that these wet packs could be cut on three sides with the side folded back to expose the food. The meat could then be eaten with a knife and fork in a conventional manner. The one problem encountered was that the juices would tend to run onto the locker surface by surface tension. Either a paper towel to catch the run off or some form of holder/tray would control this situation nicely.

4.2.8.4 Trash Management.- This may be a serious problem in the operations era.

Trash generation from the operations-type foods is a potentially severe problem. On STS-4, four wet trash bags were filled. Almost all food trash (but not all) was put into these bags. The operations-type food packages do not compact well and the trash volume is almost equal to the pre-use stowage volume. Double or triple the number of crewmembers and a significant problem is evident.

Dry trash was bagged and stored in the lithium hydroxide storage locker. This space may not always be available nor was it designed for that purpose.

Wet trash can easily become a haven for bugs and must be properly stowed. A large, easily accessed stowage area must be supplied to accommodate all the trash generated by larger crews. A trash compactor would provide a considerable amount of help in managing the quantity of trash that will be generated in future flights.

The closed ecological system must be critically evaluated. If one crewmember should become ill due to a breakdown in the system, illness could rapidly spread to others.

After subtracting the time for meals, exercise, and hygiene, it appeared that the STS-4 crew worked no more than 10 productive hours out of the scheduled 16. The difference between what was scheduled and what was delivered came out of the sleep and meal periods.

At the demonstrated work level, two shifts will not produce around the clock operations and there is some evidence that some of these overhead tasks may take longer with more people on board. Since on-orbit crew time is very expensive and extending the individual work day seems impractical, it seems attractive to look at ways to make these overhead tasks more efficient. For instance, going to the bathroom should not take any longer on-orbit than it does on the earth.

A major improvement in the efficiency of required habitability tasks should prove cost effective.

4.2.9 MISCELLANEOUS OBSERVATIONS

4.2.9.1 Cabin Noise.- The STS-4 crew was surprised at the cabin noise levels. Preflight data indicated that the SMS was noisier than the spacecraft. The sound-pressure meter was used to survey the cabin and indicated that the noise levels were the same as previously reported. Side-by-side conversation could be held satisfactorily. However, talking to a crewmember on the other side of the middeck required raising one's voice to a fatiguing level and shouting was required just to get a crewmember's attention when talking was between the flight deck and middeck. An interesting observation was that this acoustical environment did not interfere with sleep.

Based on the measured sound-pressure levels, the spacecraft on STS-4 was not unusually noisy and yet electronic communications were generally required. This condition is conductive to fatigue and inhibits good crew coordination. In the long term, these factors may become significant.

A quieter cabin should be developed for the operational era.

4.2.9.2 Freezer/Refrigerator.- The small freezer/refrigerator was evaluated on STS-4 and proved to work flawlessly. Althought the volume was small, three drink containers or cereal packages could be cooled at once. This dramatically increased the palatability of certain foods and made the beverages more pleasant to drink. Such a device with a larger capacity would greatly enhance the habitability during the operational era. The current refrigerator/freezer should be flown until a larger device can be obtained.

4.2.9.3 Flight Deck/Middeck Isolation.- For external night photography, the flight deck must be darkened or reflections from the windows will mar the pictures. It was noticed that light coming from the middeck interfered with this type of photography. Some means of isolating the middeck from the flight deck should be developed.

4.2.9.4. Time Display.- There is no time display on the middeck and one is sorely needed. Many operations are carried out on the middeck and the crewman must rely on a wristwatch for time. This is not always convenient, for example, during exercise. The middeck should include a mission elapsed timer.

4.2.9.5 Inspection of Cabin Fan Duct.- An inspection of the cabin fan duct outlet was performed. There was no free water. The windows facing overhead and into the PLB developed condensation covering the middle 75 percent whenever the window covers were installed. The condensation cleared quickly on the overhead windows after the shades were removed, however, the aft windows never cleared completely while in the tail sun attitude. The carry-on ducts for the PLB windows seemed to work properly in that air flow over the window could be felt. Nevertheless, they had no effect on the condensation. One day was run with the duct in the port window and none in the starboard window. The condensation in each window was identical. No condensation appeared on the side hatch window even though it was covered almost continuously.

4.2.9.6 Lighting.- The lighting in the middeck is generally adequate for all activities performed except 16mm photography. Adequate lighting must be provided on both flight decks if decent 16mm photography is to be obtained.

Lighting on the flight deck over C-3 is inadequate for the CDR and PLT seats. The floodlights do not shine in the right place. The crewmember's head and hand shadow a pad when trying to write. When it is dark outside, the lighting is poor. The integral lighting produces an excessive amount of heat and no use was found for the panel intregral lighting. Integral lighting for the CRT keyboard was essential for use during a darkened cockpit operation such as COAS work.

Lighting for the mission specialist's launch and entry positions was not evaluated during STS-4, but based on the SMS it appears inadequate.

Adequate illumination to allow the flight crew to read and write is mandatory. In rectifying this deficiency, consideration should be given to making the remaining light controls controls accessible from the crew seats during launch and entry.

Lockers.- The lockers are designed to be held closed by magnetic latches, however, the doors and latches are useful to hold onto for translation and restraint. If they are not latched, they can't be used for that purpose.

The doors served as very useful storage areas for small items as well as food trays.

Some of the locker doors were very difficult to latch because the thumb latch on one door interfered with the adjacent latch. The threads on some of the latches became cross threaded and impossible to tighten. At best, the male part had to be jiggled with one hand while the female part was threaded on.

Some type of net restraint, preferably sectioned, is needed in drawers with small loose items. If this is not done in two drawer lockers when the other drawer is pulled out, items from the lower drawer will float up and jam the upper drawer preventing it from being closed.

The ball locks on the sleep restraint pip pins did not firmly mate with all the locker latches causing difficulty in setting up the sleep station.

Utility Outlets.- STS-4 used all of the middeck utility outlets for both ac and dc power. Cables had to be routed from the flight deck to the middeck to support several operations.

As the Orbiter becomes operational it will not be unusual to find increasing requirements to supply ac and/or dc power to carry-on middeck equipment. The use of batteries should be avoided because of their stowage volume and weight. It is entirely conceivable that a desire to access the Orbiter data buss structure from the middeck will also materialize.

Restraints.- A system of restraints should be developed for flight use that retains as much flexibility and versatility as possible. A restraint is useful for getting items in and out of the lockers. One can restrain himself adequately by wedging his toes under the bottom row of lockers, however, this was not helpful for access to the top locker row. The toe restraint was also good for food preparation and eating with the trays installed on the middle locker doors.

A foot loop of tape around the cabin temperature controller access door was tried. When both feet were inserted and pointed slightly outward, adequate and very comfortable restraint was obtained.

The handholds on the CFES (continuous flow electrophoresis system) experiment components were very useful. Consideration should be given to some sort of removable handles for the locker doors to aid translation and locker access.

Suction-cup shoes were evaluated and worked fairly well although they had two undesirable characteristics. They did not always release easily, and more annoying, they sometimes released prematurely without warning.

A restraint is very useful for taking photgraphs from the overhead and aft windows. This area should be studied.

The whole area of restraints should be evaluated in flight in the proper environment, not in 1g. Restraint "cut-and-paste" kits should be provided for use in arriving at the most useful and versatile locations with dedicated crew time scheduled for evaluation and development.

4.2.9.10 Sleep.- Sleep requirements and the ability to sleep on-orbit vary with the individual. The middeck area is noisier (approximately 69 dB) than the flight deck (approximately 65 dB) with fans being the big noisemakers. The PLT slept on the middeck in a sleep restraint stretched across the MF43 lockers and the CDR slept floating behind the seats on the flight deck. The only time the CDR was awakened because of bumping into things was during PTC (passive thermal control). He used the sleeping bag only for thermal control. Neither crewman experienced any difficulty sleeping. The WCS is noisy and its use would probably awaken the average sleeper although it did not wake the PLT. The middeck was darkened for sleep. Light shafting in from the flight deck awoke the PLT once. The flight deck shades were usually installed for sleep by the CDR, but their use was dependent on vehicle attitude.

For shift operations, consideration must be given to isolating the sleep area from both noise and light. It should be remembered that today the middeck serves as the kitchen, bathroom, experiement area, message center and gym. With larger crews it is probable that individual isolation or at least some form of restraint may be required to make the space usage more efficient. Some method of isolating the sleep area must be found before multi-shift operations can become practical.

4.2.9.11 Speaker-Microphone Unit.- The SMU (speaker-microphone unit) was used very successfully on day 2. The ability to operate without wearing a headset, yet allowing constant air-ground communications is very desirable. This became a routine configuration for meal and sleep periods. Today's configuration is cumbersome to use because of the precautions which must be taken to avoid setting up a totally disruptive squeal.

Even the best personal electronic communications device will become a bother when worn continuously. The STS-4 crew found that removing the LWHS (Lightweight headset) during meals and certain other operations was not only more comfortable, but was, on occasion, necessary. The only configuration which worked satisfactorily was to use the SMU in PTT (push-to-talk) on air-to-ground only. Even then, when the crew transmitted, they had to insure that the second SMU was off to avoid a devastating squeal. This meant turning off all WCCU's (wireless crew communications unit) and the flight deck SMU during meals. Both SMU's were used during sleep periods to provide redundancy. This only worked because no spacecraft transmissions were anticipated.

The operational Orbiter should allow the SMU's to be used simultaneously and as an intercom between the flight deck and middeck as well as for air-to-ground. It would appear that a feedback suppression circuit could be developed to work analagously to a noise-cancelling microphone.

4.2.9.12 Headsets and WCCU.- The WCCU was an essential device for smooth operations. It found that some locations in the spacecraft caused static in the intercom loop, but it was still preferable to the headset interface unit with its inherent constraints to mobility.

The PLT's WCCU appeared to fail about halfway through the mission. The spare unit was used with no further problems.

The earpiece microphone boom design is poor. The ear hook unit that holds the microphone comes off easily with small head movements. Replacing the ear unit causes loud noise on the intercommunications loop and is very annoying to others on the loop. If one wears glasses continuously, the earpiece clip alleviates this problem.

Perhaps the microphone boom can be attached directly to the molded ear insert. In any event, the present scheme is unacceptable for long-term operations. It appears that the current unit exhibits three related problems. The ear clip is not sufficiently rigid to restrain the mass when the head is moved. The ear clip also is very sensitive to the inherent rigidity of the electronic cable. Many crewmembers wear glasses only temporarily and the LWHS design should neither depend on wearing glasses nor should it interfere with easy donning or doffing of glasses.

The most significant of these problems appears to be the lack of flexibility of the electronic cable. Every effort should be made to remove the EMI shield and use more pliable cable covers. These small forces become significant in zero g. Several candidate mountings and cables have been evaluated on the ground and look promising. They should be evaluated for inflight for suitability.

4.2.9.13 VW Pouch.- Three VW (Volkswagen) pouches were evaluated inflight, one across the airlock hatch, and one on the back of each ejection seat. These were the most useful temporary stowage devices on-board and not enough good things can be said about them. They were used to stow each day's film supply, camera lenses and filter, spare WCCU batteries, drink containers, etc. They were extremely useful for small component management on the flight deck. Such stowage devices should be made a permanent part of the ship set. However, one small flaw in the design was noted. There needs to be a stiffener behind each pocket opening so that the elastic does not draw in the back and allow the pocket to open. The concept has been proven; it only remains to refine the design.

4.2.10 <u>Crew Equipment</u>

4.2.10.1 Watches.- A good watch would aid on-orbit operations. A digital watch was used by each crewmember.

Individual crew requirements should be defined and evaluated in the SMS. The technology in this field is changing so rapidly that the practice of allowing each crewmember to select his own flight watch should be continued.

4.2.10.2 Kneeboard.- A standard pilot kneeboard was evaluated and found to be superior to the notebooks. The kneeboards did not get in the way and were very useful for taking notes during air-to-ground passes. The particular kneeboard used, however, was not considered optimum. The large head for a light was more a hindrance than useful and the light was not functional. A less bulky kneeboard should be evaluated on future flights.

4.2.10.3 Clothing.- Each crewmember evaluated a standard flying suit as well as the Shuttle twopiece IVA (intravehicular activity) clothing. One crewman preferred the flying suit while the second gave the IVA clothing the edge on convenience.

a. <u>Flying suit</u>. Both crewmen agreed the flying suit needed a different pocket design to be most useful for space operations. A thigh pocket similar to that on the IVA pants was suggested. One crewmember stated the coverall was inconvenient for WCS operations and did not lend itself to the layer concept for temperature control, i.e. there was no shirt to remove if one became warm. Both agreed the suit was very comfortable to wear. One distinct advantage, however, is the demonstrated fact that the flight suit works equally well during 1g training as it does in flight.

b. IVA clothing. One crewman did not like the two-piece concept for training since the weight of items in the pockets tended to pull the pants down. This was, of course, not a problem on-orbit. Coveralls did not generate this problem. The IVA shirt pocket design was not good for stowage of pencils since the point tended to stick into the knit fabric instead of going easily into the pocket. A pocket liner or a pencil pocket would help. One crewman complained of the tightness of the waist elastic. This is not needed for orbit operations and perhaps a non-elastic, but adjustable, waist band could alleviate this problem. Both agreed that the lower pockets on the pants were too baggy and a normal pocket would be better for tissues, etc. Both also agreed that the pants were too baggy.

4.2.10.4 Entertainment.- Some sort of music playback is needed for entertainment. The recorder carried on STS-4 was of poor quality. The requirement that only GFE tapes could be used and all music had to be re-recorded on them is particularly annoying and unreasonable. Commercially available tapes should be authorized for flight. A good recorder/sound system should be a permanent installation for the Orbiter for the operations era.

4.2.10.5 World Map.- The roller world map was used throughout the flight. It was the only display that allowed looking ahead to which ground stations would be crossed and over what part of the world the spacecraft would fly. This information is essential for planning.

The map is cumbersome to use at best. First, the AOS/LOS program must be exited in the HP-41 calculator and the MET (mission elapsed time) program called, this taking several minutes. The longitude of the ascending mode and minutes past the ascending mode are then calculated in the MET program. The event timer is set to the time past the ascending mode and counting up. The roller map is then adjusted to put the ascending mode at the right place. The AOS/LOS (acquisition of signal/loss of signal) program must then be recalled to get the AOS/LOS displays (several minutes). This process must be repeated every couple of orbits to keep the map current.

A substantial portion of the STS-4 mission activity was tied to the spacecraft's position over the earth and its relative attitude. The crew should be able to quickly determine their position and attitude with respect to the earth to efficiently execute the flight plan and provide the essential flexibility necessary for them to capitalize on their unique vantage point. This capability will always be paramount in achieving productive use of man in space.

Until TDRSS (tracking data and relay satellite system) becomes routine, the crew will require a big picture of the communications capability which is also ground-track dependent. Today, the best way to do this is with the world map.

Today's operations display shows a pictorial antenna pattern which has little utility. If this operations display were replaced by an electronic world map, it would be the most useful display in the spacecraft. Since knowledge of earth relative position and attitude is essential for good flight planning, a display should be immediately developed which provides the current position, future ground track, major earth features, relative spacecraft attitude and day/night terminators.

4.2.10.6 HP-41 Calculator.- Four HP-41 calculator-type computers and a card reader were carried onboard. Three had CAP alert programs and the other carried an AOS/LOS program as well as a stopwatch and countdown alarm function. The large number of CAP alerts utilized in the planned mission required breaking them down into three load segments. One segment was preloaded into each of the CAP alert units to avoid having to use the card reader or real-time loads. Both the card reader and printed alert lists were available in case one of the calculators had to be replaced.

Each day's activities were stored with a MET time tag. An alarm sounded as each event came due. The purpose was to relieve the crew of clockwatching and allow them to concentrate on any particular task without fear of missing a time critical event. This worked very well in training, but did not work well in flight for two reasons. First, the alarm tone was too faint to be heard from more than several feet away in Columbia. Second, the timer module stopped on numerous occasions. The concept of using audible and visual aids as a means of improving crew efficiency on-orbit was demonstrated during training. Once the crew incorporated these tools into their procedures, it became very difficult to do without them on-orbit. It is unlikely that the computer tone volume will be increased. However, an external tone booster should be very simple to build. Just as a point of interest, the crew did try using an HIU to put this tone on the SMS intercom. The SMS would not pick up the computer frequencies even though it did work on the CFES. This was not evaluated in flight.

How the crew assures themselves that the alert program time function can be relied upon is equally as important as and potentially more difficult to solve than the tone volume issue.

The nature of the HP computer timer problem has not been identified. The crew believes the on-orbit problem was the same as encountered several times during SMS training. Prior to flight, this behavior had been attributed to specific timer modules since this problem could not be repeated in the office. In flight, all three alert program calculators stopped at least once, although the AOS/LOS unit ran the entire mission. In retrospect, the crew has never seen the AOS/LOS program halt, only the alert program. Therefore, procedural error or EMI (electromagnetic interference) are the current candidates.

Even without these two problems, the HP computer utility would still have been compromised because of the massive CAP changes which were invoked. These could have been entered manually had the time been provided, however, a much more versatile solution would be to uplink this from the ground. Eventually, a basic Orbiter capability should be the ability to update both summary and detail CAP's automatically on-orbit. In fact, it should even allow execution directly from the CRT using it as a master checklist. The cost savings which may be realized by replacing printed pages with magnetic tape just might pay for itself as well as enhance the operations era capabilities.

This is a fundamental crew tool which should be permanently implemented in the Orbiter DPS (data processing system). As an interim measure, increased volume on the tone and a fix for the program halts is required.

4.2.11 Operational Flexibility

NASA-JSC should strive to achieve flexibility in the operations era for such things as Velcro installation and launch stowage. Velcro hook and pile should be carried in adequate quantities on each flight to allow installation where needed. Postflight safety inspections should be the only requirement and thereby eliminate costly mapping and removal of unmapped velcro.

Problems were encountered close to the flight date from getting last minute required items onboard the spacecraft. There will probably always be last-minute stowage items and crews in training should not have to devote precious time to such worries.

While stowage must be controlled, the present systems seems unwieldly. The STS-4 crew was told there was no more stowage room even though much of the locker space was occupied by foam cushions. When this condition was challenged, the crew was reminded of the high cost of producing new stowage drawings. Now that all locker stowage is managed locally at JSC, it would appear that a streamlined system could be devised that would provide both flexibility and control at a reasonable cost. Why not reserve one locker specifically for late changes?

4.2.12 Mission Documentation

Mission documentation is often taken for granted, however, it can be a major output of any flight. This documentation takes several forms, still and movie pictures, VTR tapes, voice tapes, written notes, and voice transcriptions. The use of each also varies considerably from that required to fulfill mission objectives to postflight PAO pictures. Each use must be identified preflight and the appropriate method of documentation selected. Any on-orbit documentation takes a surprising amount of time and should be streamlined as much as possible. The postflight period is also quite active and does not allow much time to search for data. If the data are hard to acquire, it generally is ignored.

4.2.12.1 Microcassette.- The STS-4 crew made extensive use of the microcassette recorder for general thoughts and observations. This approach has the virtue that it is relatively easy to get hold of these cassettes as memory joggers postflight. The intercom and air-to-ground channels can be provided, however, each segment has to be asked for individually by MET and may take several days to retrieve. STS-4 intended to use this intercom data source only for launch and entry to minimize the data retrieval problems. Launch and entry happen fast enough and contain so many events that one's memory can easily be fooled. During ascent, the CDR gave a running commentary of what was happening, what the crew was doing and the current velocity or event. This made the reconstruction relatively simple and reminded the crew of numerous details they had forgotten. During entry, the commentary was significantly less and this has made the reconstruction of events much more difficult and unreliable. This is one area where practice in the simulator would have helped.

4.2.12.2 Photos.- Photo documentation presents a unique problem depending on the type of photo and camera used. The 35mm now has a data back that prints hours, minutes and seconds on each frame if desired. This is a big help, but would be much more useful if days, hours and minutes were recorded. The option to print seconds should be retained for some engineering data.

a. 70mm: The 70-mm system is used primarily for out-the-window scenes and currently has no data back. These scenes are generally taken when the opportunity presents itself and for some purpose. Today, the crew must rely upon their memory of the what and why, and make a voice or written note. Memory seldom is accurate a week after flight and unorganized notes are almost impossible to correlate. Adding to the problem is the coarseness of the 70-mm film magazine counter. A day/hour/minute data back is available and should be used for all out the window pictures. Some commercial still cameras now feature a limited voice recording capability. This should be investigated for Shuttle applications.

b. VTR: The VTR system is a powerful tool for engineering data, training material and general public relations. The cabin cameras have a tremendous depth of field and low light level capability. One advantage is that cameras can be set up to document a long sequence of events such as deployment of an upper stage. The camera can be placed out of the way and the VTR left running. The shortcomings of the current system are:

1. The VTR should not be continuously run longer than some TBD time because of potential thermal problems. If this is a valid contraint, an audible alert should be triggered either by a timer or a temperature sensor.

2. There is no alert when the VTR runs out of tape.

3. The camera is very bulky and therefore hard to manage for some shots.

4. The VTR cannot dump its audio channel to the ground in real time.

5. The tape counter on the VTR is all but unusable because of its location.

6. A fast-scan feature would be a very useful addition to aid in air-to-ground editing and playback.

c. 16-mm: The 16-mm camera system is antiquated. It should be replaced with a system which includes an automatic lens, through the lens viewing and enough film to allow at least a 24 frames/second film rate. In addition, the middeck illumination needs to be increased so that the lens does not have to be used at its largest f-stop. Incorporation of the above will insure movie vs. sequence photos, proper focus, scene content and exposure. The current system has been pushed to its limits and requires an inordinate amount of crew time and training.

d. Future Systems: Speech recognition devices are currently available today. Future spacecraft documentation systems should consider this as a way to not only direct voice comments to a dedicated recorder, but could also provide a way of cataloging comments by topic to speed up the postflight and inflight review.

5.0 OPERATIONAL OBSERVATIONS

This section is intended primarily for the members of the Astronaut Office. In addition to objective observations, a number of these comments include opinion, judgement and the operational philosophy of the STS-4 crew.

5.1 PRELAUNCH

5.1.1 The Health Stabilization Program, as implemented for STS-4, had a minimum of annoyances. In fact, the semi-isolation contributed to the relaxed pace of the final week.

5.1.2 The KSC protocol is excellent in content and execution. The only area recommended for review is the now "traditional" PR (public relations). Having the press waiting at the airport for the arriving crew is a risky practice. The STS-4 crew diverted into the Shuttle landing facility due to weather and left the press standing in the rain at Patrick AFB. That is bad PR, but PR committments should not be a factor in deciding the best place to land.

The "last supper" aura of the launch day breakfast should go because it runs counter to the operational impression we are trying to convey. Granted some PR is appropriate, maybe a mini-press conference could take the place of these other events.

5.1.3 Weather can be a factor in determining when the crew leaves for KSC and the route selection. The STS-4 crew had to divert into Tyndall AFB enroute. Honoring the spirit of the health stabilization program made this unanticipated turnaround awkward. Consideration should be given to having a primary contact go along when weather is a factor.

5.1.4 Since the launch-2 day T-38 local aerobatic flight was missed, it was rescheduled immediately following the launch-1 day STA (Shuttle training aircraft) flight and was conducted from the Shuttle landing facility. This worked very well and should be considered as part of the routine.

5.1.5 The vehicle systems briefings were streamlined by having the charts sent to JSC at the beginning of the week. This allowed the crew to do their homework and eliminate discussion of things everyone was already familiar with. This procedure saves time for everyone and is recommended for continuation.

5.1.6 The discomfort experienced from being strapped in on the pad is minimal for the first hour and a half, then increases noticeably during long hold periods. Partially unstrapping allows enough movement to significantly relieve pressure points and allows much greater stay time. Long duration comfort of the operational seats in the vertical position should be evaluated and if necessary, some thought might go into developing techniques for partially unstrapping and unaided resecuring of the restraints. The external tank nose can be seen from the cockpit if the seats are at the top of their vertical travel.

5.1.7 The STS-4 crew had a late morning launch that put a lot of sun in the windows. It was noticably warm with the sun shining directly in, but not uncomfortable with the suit flow. The sun reflecting off the PLT's suit made it difficult for the CDR to read CRT 2 on the pad because of reflections, however, this problem disappeared shortly after launch. The lighting controls cannot be reached when strapped into the launch position so it is important to consider adequate lighting before the ASP (astronaut support personnel) departs. This may be significant for late afternoon launches where the transition to darkness may occur prior to the completion of the OMS 1 maneuver.

5.2 ASCENT THROUGH OMS-1 MANEUVER

5.2.1 The ascent felt very much like the Saturn except that the vibration and g levels were reduced. Previous crew descriptions were quite accurate. The Shuttle second stage qualitatively felt smoother than either the S-II or S-IV. There was no buzz or indication of POGO. The major motion sensations associated with ascent events were the prelaunch SSME slew, lift-off, SRB tailoff and pre-MECO throttling. The air noise was obvious below 35,000 ft. Vibration frequency and magnitude seemed to reach their peak near 35,000 ft. The vibrations diminished noticably around Mach 2 (approximately 70,000 ft) and became very low by Mach 2.7.

The only real indication of SRB separation was the flash from the separation motors. The acceleration change at SRB separation could be read on the meters, but was not physically noticed. After staging, the two window-mounted cameras could clearly be heard. At approximately 2g, body movement was noticably affected and by 3g it was very restricted. Much to our surprise, breathing became conscious at 3g. At 3g and prior to MECO, the SSME shutdown push button switches were very hard to see and reach.

5.2.2 One of the test objectives called for a visual assessment of any debris which would be seen around the vehicle during ascent. Specific questions concerning size, shape, color, velocity and source were added to a post-insertion debriefing guide. The STS-4 crew tried to comment as often as possible during boost using the intercommunications tape recorder to document these observations in real time.

The first observation was made after completion of the roll program. There were a lot of small particles going by that the CDR described as looking like flying in a light snow shower. This was most apparent looking out the CDR's side and quarter windows. This apparent assymetry may be real or due to the sun angle.

This same "snow shower" was observed several more times during ascent. The apparent density, velocity, and appearance of these sparkling particles appeared to remain constant throughout ascent. In fact, this same phenomenon was observed after ET separation and again following OMS 1 maneuver.

These particles were noted throughout the flight. Their appearance remained uniform although the concentration seemed to diminish as the mission progressed. Towards the end of the mission, there were very few particles, although they seemed to be more prevalent following a thruster firing.

5.2.3 At ET separation, the glow from the downfiring thruster could be seen. This was not the case on-orbit and may be due to the low altitude.

5.2.4 The automatic-TAL software appears to work very well and should deliver the Orbiter to a landing posture with a high degree of confidence. At the end of TAEM (terminal area energy management), however, the CDR is solely responsible for landing a heavyweight vehicle on a short runway with no aids other than his judgement and experience. The amount of effort the program expends to assure that the Orbiter can be stopped on a 15,000-ft fully supported runway seems inconsistent with our approach to a TAL landing. Both ROTA and DAKAR are only slightly longer than 10,000 ft and today neither are equipped to aid the pilot in executing a landing. As a minimum, PAPI's should be installed at any TAL landing site until HUD (heads up display) performance has been shown to be inadequate. Some form of aim point may always be required.

5.3 ON-ORBIT

MCC noted that one of the RCS DAP pushbutton switches on panel C-3 had not made all of its contacts. Postflight inspection showed that if the switch was lightly depressed enough contacts would be made to cause the function to respond, but not all contacts would be closed. The STS-4 crew noted that switches on panel C-3 were awkward to push in zero g unless the crewmember was restrained or used some means to help apply force to the switch. In zero g, the body's inertia may not always be enough to apply the necessary force to these switches. For operations transitions where the DAP (digital autopilot) switches had to be held down, the crew found it necessary to use their spare fingers to grab the panel overlay to apply continuous pressure to the switch.

The EMU prep activities were exercised in the airlock by a single crewman. All procedures worked well. The lower torso assembly could not be attached to the hard upper torso without the use of the donning aids. With the donning aids, the task was easy. The second EMU was pressurized and left mounted on the airlock wall to allow evaluation of mobility with two pressurized crewmembers in the airlock. Only the manned EMU used the portable work restraint. The ability to turn around and over, as well as reach hatch mechanisms was found to require preplanning, but was feasible.

It was noted prelaunch that the air flow on the PLT's vent was much higher than that delivered by the CDR vent. Sometime on-orbit, it was noticed that this flow pattern had been reversed.

The RMS control precision and harmony was excellent. The CDR, with very little preflight practice, was able to quickly execute a grapple task. The RMS rate hold capability was demonstrated by pointing the end effector CCTV cross hairs at a cloud and allowing rate hold to maintain this pointing even though the spacecraft was in an inertial attitude hold. The auto function was very smooth and corrections were easy to make although seldom required.

The RMS unloaded tests appeared to validate the preflight predictions of arm response to PRCS firings. The amount of flexure and frequency is such that they must receive special care when manipulating large or massive payloads. The arm flexure was hard to see when just watching it against the earth background. It looked like it was steady against the moving earth features and then would slowly move in apparent jumps. When viewed through the CCTV or against parts of the Orbiter, the natural periodic motion was quite apparent.

Star tracker operations normally were very rapid. On only one occasion did the star tracker seem to take an unusually long time to acquire a lock on. The only obvious difference in this case was the presence of a brightly illuminated horizon in the general direction that the -y tracker was pointed. The star was eventually acquired although it took several minutes.

The PRSD stratification test required two 180° pitch rotations. These were executed using the pitch axis in accelleration with roll and yaw in DRC. It was noted that after returning the RHC (rotational land controller) to detent in the accelleration mode, the vehicle rates, as displayed on the ADI, continued to accelerate for a short period.

When the flight control power was turned off following OMS 1, the DAP downmoded from auto to manual and fired some thrusters. This was the only occurrence on STS-4.

The WCCU batteries were replaced as part of the presleep activities each day rather than according the CAP schedule. The batteries held up with this duty cycle.

The PLT noted icicles on the center SSME engine bell. They disappeared sometime before the end of day 2.

The PLB liner appeared to be intact except for a small opening approximately 6 inches long under the payload pallet.

Both inboard and outboard elevons could be seen and they appeared to slowly drift throughout the mission. No correlation between circulation pump operation and drift was noted.

The theodolite was very easy to use and its readings appeared to be very repeatable. The PLBD centerline targets are very difficult to find aft of about the mid PLB. Use of approximate angles, determined preflight, and the handheld flashlight made this a viable task.

During the RCS plume survey, the crew had an opportunity to pay close attention to RCS thruster characteristics. In general, the forward primary thrusters shake the vehicle quite impressively. The signature is one of two large amplitude shocks for each firing. The first shock occurs when a firing is initiated and the second, when it is terminated. Both are felt even on an impulse burn. The aft primary RCS exhibits the same characteristics, but the cabin level shock is substantially less than with the forward thrusters. There are no sounds during the firing between start and stop. The plumes from both the primary and vernier thrusters can be seen plainly at night or against a dark background.

The STS-4 crew noticed that the up firing aft thruster plume appeared to have a second emanation when firing was terminated. This was not noted for any other thrusters.

The PLB CCTV was used to view the earth at night in moonlight. The camera easily picked up stars, clouds and lightning as well as vernier thrusters. PLB details could easily be seen in moonlight. The top of the atmosphere (approximately 90 km) was easily distinguishable as distinct from the earth's horizon.

Both crewmembers could easily feel vernier RCS firings by day 5. These were perceived as a low amplitude, soft wiggle. They were more perceived than felt.

Items are routinely lost on-orbit, i.e. if unrestrained, they float away. Typically, they could be found on the DEU screens on the flight deck and behind the DFI package on the middeck.

The micro-cassette recorders were used to record thoughts and data for use in preparation of the postflight debriefing. The crew used these extensively in training, but found there was not as much time to use them on-orbit as had been anticipated. However, their use provided much more data than would have been obtained otherwise. They worked perfectly and did not even require a battery changeout during the mission.

The top of the glareshield makes an excellent stowage location for small articles. Temperatures did not become high enough to cause any concern.

The humidity in the spacecraft remained at a comfortable level throughout the flight. The temperature of the spacecraft varied with the attitude, being warmer in PTC than in tail-to-sun. The temperature was slow to respond to changes in the controller setting. The middeck remained warmer than the flight deck. During a DTO that called for the flood and integral lighting to be on, it was noted that they radiated considerable heat. Both crewmen perspired profusely during the test while on the flight deck. The cockpit was slow to cool at the completion of the test.

What an observer can and cannot see from orbit has received a lot of discussion. All crews have reported that they saw a great deal more than what shows up in their pictures. STS-4 was no exception. Examples of things noted with the naked eye from 160nmi. altitude were: ship wakes, major freeway systems, the VAB from over Key West, runways, population centers, and aircraft contrails were seen as shadows on cloud tops.

Looking through the 10-power binoculars or through the 250mm lens on the 70mm camera, ships of destroyer size could be seen, but not identified according to type.

Ten-power binoculars are the maximum magnification that are practical for hand-held use. Gyro stabilized binoculars should allow at least 20-power. One additional feature that should be included in any optical magnification system is a way to easily switch between high magnification and no magnification. This is necessary to allow orientation and target acquisition.

How tired should the crew allow themselves to become? The STS-4 crew tried to remain relatively alert as long as a de-orbit opportunity existed. Once the nominal access to recovery sites passed, the crew allowed themselves to become more fatigued to the point where anything other than emergency deorbit with its attendent adrenalin would not have been prudent. This subject is worth thinking about preflight.

5.4 PAYLOAD SUPPORT

The CFES equipment and procedures worked well. Preflight, the crew was concerned that they might not be able to hear the CFES alert tone if they were on the flight deck. A test was conducted on day 1 which confirmed that an audio boost would be required. The middeck ATU was used in VOX with an HIU which was taped adjacent to the CFES speaker. This worked well.

The CFES was designed to a specification alert tone frequency and volume. The Space Program has encountered this problem before and apparently there is a need for a spacecraft unique audio alert criterion.

The volume on the CFES tone should be increased for future flights. NASA should develop an adequate audio alert tone specification or if one exists, insure it is made available to all Shuttle customers.

Flight day 3 was expected to be the most demanding day of the mission because it involved two very long RMS/IECM (induced environment contamination monitor) time dependent sequences. The PLT had practiced these sequences extensively preflight and determined that there were virtually no margins in the timeline. To add to the difficulty, these two sequences were constrained by a scheduled burn at the end of the last one and a minimum time for the IECM to be parked on the REM in between. The entire flight planning community had tried unsuccessfully to relax this timeline or its constraints for months prior to the mission.

An RMS anomaly, discovered during the initial checkout, set the day's timeline back one hour. This would have destroyed the rest of the day's timeline if the IECM representative had not immediately volunteered to cut the IECM/REM time to 30 minutes between sequences. The PLT then ran the entire set of sequences and picked up three RMS shopping list activities while meeting the burn constraints at the end of the day. The first IECM sequence took 6 seconds longer than the 2.5-hours scheduled. The primary reasons the PLT was able to accomplish this feat were that he had trained extensively preflight then worked at an unforgiving pace in real time, experienced no further anomalies, and finally, the MCC team exercised exceptional communication discipline and anticipated every required input. The only unfortunate aspect of this day was that after it was over, the IECM representatives discovered that the IECM internal sequencer had not responded properly and was not in the proper configuration for the final two hours of the plume surveys.

The reason this day's schedule was so messy can be directly related to the IECM thermal constraints. Apparently, these were not hard constraints since they were substantially relaxed in real time. The loss of data occurred because of the total absence of any ground or on-board monitor capability of the IECM. Its malfunction was diagnosed parametrically during the evening and operation restored later in the mission. The fact that the crew worked very hard for several hours on a non-functional objective is unforturnate to say the least. Now the survey must, presumably, be reflown and that time which could have been used to do other activities, was essentially wasted.

The IECM was not designed for the use we put it to. Rather, it was adapted. Nevertheless, this experience raises a question about what role the operators should play in experiment design. All of the design shortcomings, which made the IECM operations awkward and unrewarding could easily have been circumvented had they been addressed early in the design cycle. The operators should be involved in the design review process. This should be mandatory for NASA payloads and optional for commercial ones.

The NOSL experiment required a disproportionate amount of crew orbit time because of the nature of the experiment and the hardware design. The purpose of the experiment was to photograph lightning discharges in both the daytime and at night. The equipment was very awkward to use from the spacecraft cabin due to the number of components and their size. The night time photography was further compromized by the requirement to darken the cabin to avoid window reflections and the fact that the optic train, including a diffraction grating, attenuated light to the extent that lightning discharges could not be seen through the lens.

Lightning is not scheduled so it was decided to let the crew use their judgement in selecting photo opportunities. During the mission, MCC "suggested" specific target areas which required a lot of crew time to support. A 1-minute photo sequence usually required 5 to 10 minutes of crew time and at night affects both crewmembers because of the need to turn out the lights. After all of this was done, the crew believed that their own targets were more active than those they were sent after.

The best way to operate this type of experiment is with one of the PLB CCTV systems since these cameras clearly "see" lightning, can be pointed and tracked over a wider field of view and do not require the cabin to be darkened.

The following observations should be considered for future experiments.

a. Experiments to be flown in the Orbiter cabin should be coordinated with operations personnel early in the conceptual design phase to preclude the problems encountered with NOSL.

b. Experiments which are better managed on-orbit should be.

c. Experiments which require substantial crew time must be recognized and planned accordingly.

5.5 DEORBIT, ENTRY AND LANDING

The last crew activity on day 7 was a detailed review of deorbit firing procedures and entry/landing techniques. This review was conducted at the flight deck forward station and used the cue cards, checklists, etc. in their entry day location. This was not only a good mental exercise, it also verified that all entry data was indeed in place.

The "transdap" pulse mode is relatively small and requires a lot of RHC activity to counteract the evaporator and APU exhaust venting.

Once in MM304, two aft RCS yaw thrusters are fired as a minimum. They were as noticable as the forward thrusters. The crew could not tell if this impression is due to their increased personal sensitivity or some other phenomenon. The aft thruster plumes were observed causing a glow around the vehicle nose prior to sunrise and after EI (entry interface).

The entry control system seemed very tight. The number of RCS firings, as indicated by the RCS activity lights, appeared to be less than what is normal in the SMS.

The ionization glow was basically reddish orange compared to the white sheath noted during Apollo lunar entries. The crew did not observe the area of recombination. All evidence of this sheath disappeared at sunrise.

Just after the first roll command (approximately 300,000 ft altitude) both crewmembers commented on what they perceived as turbulence. The amplitude of this sensation came and went throughout the entry. Preliminary postflight analysis indicated that this may have been a vertical fin bending mode.

The combination of 40° angle of attack and an 80° bank angle produces some unique visual sensations when looking down at the cloud tops going by sideways.

At about Mach 17, the CDR felt it appropriate to adjust his seat up to maintain the proper instrument panel and window picture.

Shortly after PTI-0 (structural) was selected at Mach 2.1, the CDR felt the vehicle "shake". Preliminary data indicated this may have been caused by a low-frequency roll oscillation seen on previous flights.

The transonic buffet is very noticable and peaked at Mach 0.9 followed by a very rapid damping.

CSS (control stick steering) was used for S/B (speed brake) control from Mach 0.9 through rollout. The auto system commanded S/B retraction at approximately 4000 ft altitude. Approximately 50-percent S/B was retained until 2500 ft with an airspeed of 287 knots. CSS was used from Mach 0.9 (pitch and yaw/roll) to approximately 45° of HAC turn remaining. Auto was then selected with a mode to autoland at 9600 ft altitude. CSS was reselected at 2500 ft and maintained through rollout.

The landing was near nominal from preflare through rollout. Preflare was initiated on a radar altimeter cue with the ADI pitch rate used as an aid. The nominal preflare initiation altitude is too high for the CDR to execute it repeatedly using out the window perspective only. This does not mean it cannot be done safely - just not repeatedly. The landing gear was deployed at approximately 400' altitude and could be felt, but not heard. A very shallow final approach was flown to minimize pitch corrections near the runway. During the entire approach, the PLT called altitude and airspeed. This is not an ideal data transfer mechanism, but is required until the HUD (head up display) becomes available. The CDR relied more on the PLT's altitude calls than he did on his perception of altitude during the final flare. At touchdown, the CDR felt he was actually higher than what the PLT was calling out. The final flare was controlled by flying pitch attitude changes, in a semi-open loop fashion, to control the PLT's altitude callouts. The CDR had intended to make some grease pencil marks on his window to aid in this task, but a survey of the windows prior to entry indicated that there were enough natural smudges to function as attitude references.

Touchdown occurred near 200 KEAS (knots estimated airspeed). The nose was left at the landing attitude until the pilot callout of 180 KEAS when a 1-degree/sec pitch down maneuver was initiated. The RHC was returned to detent as the nose approached the horizon and not touched again until the nosewheel was on the runway when full nose down was commanded to off load the main gear. The nosewheel touchdown was much softer than had been anticipated. Full S/B was selected after main gear touchdown. No conscious directional controls were applied during rollout. Braking was initiated at 140 kts ground speed. The target value of 10 ft/sec^2 deceleration was not achieved. The peak value noted was 9 ft/sec^2. The crew believed that the antiskid was cycling during the initial braking. The CDR was frustrated by this inability to obtain either the target or a smooth level of deceleration. Braking was relaxed as the Orbiter slowed to less than 60 kts with lots of runway remaining. The 4000-ft remaining marker was slightly ahead of the Orbiter at wheel stop.

The Orbiter is a difficult aircraft to land. Successful landings require very high concentration levels and a conscious effort to minimize anything, but very minor pitch corrections below approximately 100 ft altitude. The pitch control loop is very crisp and acts more like an attitude hold rather than a rate command system. A natural characteristic of the Orbiter geometry is that the large amount of elevon area results in a center of rotation which is ahead of the vehicle's nose rather than near the c.g. (aft of the cockpit). This means that the gear initially goes down rather than up when the nose is raised. The period between the time when the pilot commands a pitch up and the time the gear sink rate is reduced is almost one second. This means that the pilot cannot tightly close the loop on h, but rather must estimate how much pitch change is required at his current airspeed to effect the desired change in h. This characteristic is very undesirable, but can be accommodated as long as trajectories which avoid abrupt control inputs are used. The pilots task then is to insure that his final approach is shallow and stable. These characteristics are sufficiently subtle to make the danger of landing short very real until the HUD becomes operational. Maximum brake performance has not been demonstrated yet, so the pilot cannot afford to plan on landing long just to insure he does not land short.

The STS-4 experiences prompt the following recommendations.

a. Do not plan a runway landing until the HUD has been shown to eliminate the possibility of reasonable pilot technique producing a short landing.

b. Demonstrate maximum braking performance before it is required to remove undue conservatism from the landing rollout calculations.

c. Develop external trajectory cues to aid the pilot in smoothly executing the preflare to inner glideslope transition.

d. Eliminate the 6 ft/sec landing sink rate restriction as soon as possible.

Prior to STS-1 we were concerned about entry navigation sensors polluting the PASS state vector to an unflyable degree. To protect against this potential, the crew elected to inhibit navigation sensor updates into the BFS. This seemed like a prudent technique for the first flight. NASA now has four flights and untold hours of testing and simulations behind us with no evidence of this occurring. Nevertheless, NASA continues to inhibit the TACAN and ADTA's in the entry BFS navigation. On STS-4, the MCC requested a state transfer to improve the BFS navigations estimate at a time when there were other things for the crew to do. The crew encountered this often in simulations also.

It appears that NASA may be increasing the crew workload on most entries solely to protect against a problem NASA have been unable to create. If this is correct, the concept of a BFS virgin navigation state should be reexamined.

5.6 FLIGHT CREW PHYSIOLOGY

5.6.1 Crew physiological adaptation to and from the zero g environment has received a lot of attention since the beginning of spaceflight. It appears that there is a great deal of individual variation in this adaptive process which makes it difficult to discern generic symptoms. The following observations are offered solely to describe two sets of experiences.

The STS-4 CDR had one previous flight of approximately 10 days' duration during Apollo. This experience allowed some comparative observations although the 10-year interval between flights limits the precision significantly. This was the PLT's first spaceflight.

Preflight, both the CDR and PLT were evaluated on the rotating chair using a standard protocol. The CDR was surprised to find that his tolerance to the rotating chair was minimal. On his first ride, the protocol had to be terminated early due to nausea. Since the CDR had no problem during Apollo and had never had any difficulty in aerobatics or on the KC-135, this test was repeated but produced similar results. The PLT on the other hand had no problems whatsoever with the chair protocol.

During the week before launch both crewmembers flew several local sorties in the T-38 emphasizing maximum roll and turning performance maneuvers. The last flight was at launch-1 day following the STA mission at KSC.

Immediately after insertion, while the crewmembers were still strapped into their seats, the only evidence of zero g was the behavior of objects floating around the cabin. Some time later, both crewmembers noted that the other crewmember had "fat" faces. The CDR noted that he needed his reading glasses to comfortably use the FDF in any lighting condition. This was in contrast to his experience in training where he seldom needed to use his glasses except with poor lighting or poor Xerox copies. The PLT had not noted any change, however, after being asked, he thought his corrective lenses did not seem as strong on-orbit as on the ground but the difference was not enough to cause any difficulty.

Both crewmembers began orbit operations by moving very slowly, minimizing translations and rotations, turning the body rather than the head and attempting to maintain a good visual frame of reference. The PLT stayed on suit cooling until time to doff the EES while the CDR was off cooling for approximately 30 minutes during aft flight deck reconfiguration. Neither became warm and the suits were relatively dry when doffed. Within 30 minutes, the CDR decided that moving slow was an unnecessary precaution. This experience was identical to his Apollo experience. The PLT moved slowly per plan and seemed to be enjoying zero g for several hours before he commented on having a headache and a "knot" in his stomach.

These symptoms came and went throughout the remainder of day 1 and into day 2. Toward the middle of day 2, the PLT experienced two sudden waves of nausea. The first one passed quickly and the second resulted in one short episode of explosive vomiting. As soon as this episode was over, all symptoms disappeared permanently. The effect of these symptoms on the PLT's performance was minimal. The primary result was that he did not enjoy the first 24 hours as much as the rest of the flight.

As the mission progressed, both crewmembers noted an increased sensitivity to low-level accelerations. By the end of the mission, each vernier thruster firing could be sensed whereas they were transparent on the early days.

Appetite was generally diminished, however, it is not obvious if this should be attributed to the environment or to the pace of crew activity. The appeal of the food itself lessened during the end of the mission and by the evening meal on day 7 the crew had to search the pantry and meal packages looking for something they wanted. It appeared that although each food retained a distinctive flavor it all took on an aura of sameness. Perhaps one way to describe this would be as if the food had all picked up a common unappetizing taste/smell.

During entry, both crewmembers experienced a strong sensation of pitching up shortly after sunrise, possibly associated with a small bank adjustment. The vehicle drag acceleration at this point was quite low. The CDR experienced a subsequent tumbling sensation when turning his head while flying around the heading alignment circle just prior to landing.

Time compression has been previously reported during entry and this mission was no exception. Unlike the CDR's previous experience with dense timelines where it is not uncommon to feel that the clock is running fast, he described this sensation as one where the clock is normal but it is taking longer than usual to execute mental activity.

During the entry α sweeps, the vehicle n_z varied between 1.8g and 0.5g yet neither crewmember was aware of these changes. This is in stark contrast with other comments about their increased sensitivity to low-level accelerations.

Postlanding, both crewmembers felt extemely heavy. The CDR was not sure he was going to be able to get out of the seat without assistance. He discovered that he had adequate strength to do anything he wanted, but it required an attempt to overdo major motions. He described it as being analogous to a closed servo loop with inappropriate gains on the output. In contrast to this experience, he never had any trouble working on the treadmill with the ~160-pound bungee forces. In reflection, one difference seems to be that the treadmill activity can be characterized as applying reactive loads, whereas the initial 1g activities involved the body sending out a command open loop and waiting for a response. Another obvious difference is that the postlanding activity came some time after the application of entry g. The CDR believes that the postlanding "heaviness" was much more pronounced following the Orbiter landing than he remembers from Apollo, although the STS mission was of shorter duration. The only differences noted during entry were the g-time profiles and the relative body g vector orientation.

Typical coordination problems were experienced postlanding with a very rapid relearning curve. The crew walked around and did mild exercise in the middeck for about 20 minutes before exiting the Orbiter. The initial efforts to climb down the ladder and walk around the Orbiter took substantial concentration. Several hours after landing the crew still had to think about walking, but could do it satisfactorily. By the time the crew arrived at Ellington they were able to negotiate normally.

During the flight from Edwards to Ellington, the crew noticed that their appetites had returned and the CDR no longer needed his glasses.

The crew had not had a great deal of sleep during the mission, however, they were not aware of any prolonged fatigue. Upon return to Houston they were both exhausted. After several days, the physical fatigue had passed, but the mental fatigue seemed to linger for several weeks. This emotional letdown after the mission has been experienced on previous flights and seems rather normal considering the pace of the preceding year. It is real and should be considered in planning postflight activity.

5.6.2 Throughout the flight, the crew had been forcing fluids to insure that they avoided dehydration. This resulted in far more urinations than would be considered normal. The crew had been briefed that on entry morning they should augment the forced fluids with four drinks and salt tablets. This last quart was to be consumed within 2 hours of deorbit. The donning of the EES 3 hours prior to deorbit complicated this task. On day 8 the crew prepared the four entry drinks and stowed them and the salt tablets in R-5. The PLT and CDR drank two drinks 1 hour before the deorbit and drank another after the deorbit maneuver. The PLT drank his last just prior to EI while the CDR saved his fourth for postlanding.

The requirements for forcing fluids during orbital operations and on entry morning should be reviewed with the aim of curtailing as much as seems prudent.

5.6.3 The IECM contamination survey required a top sun condition. The CDR watched the RMS response out his overhead window for approximately a minute. Later in the afternoon, his eyes were very tired and he had trouble keeping them open. This condition eased by the end of the day and was not noted after that. Even short periods of looking near the sun must be procedurally avoided.

5.6.4 Exercise is extremely important to the crew for several reasons. Just as in 1g, exercise improves one's outlook and reduces tension during a tedious day's work. Exercise helps to maintain muscle tone which is important to postlanding readaptation to 1g. The CDR found that exercise cleared his stuffy sinuses and that they did not get blocked as often as on his Apollo flight. Measurements taken pre- and post-exercise showed a reduction in head circumference and increase in leg circumference.

Because of setup and tear down time and personal hygience required post exercise, 50 minutes to 1 hour should be allowed per crewman for 20 minutes of exercise. Exercise periods should be preserved with a high priority in the daily flight plan.

The location of the treadmill allowed use of the airlock and DFI as hand holds and support. Some form of hand support should be available during exercise. The high loads applied by the bungee/harness unit are large enough to cause an unjury if someone slips without any hand grips. The protocol used on STS-4 was left up to each crewmember. The PLT exercised rather vigorously while the CDR used a heart rate profile with five minutes at each level 90, 110 and 150. The electronic monitor should always be available to avoid boredom and allow exercise quantization. The treadmill made quite a racket and shook the deck panels. The crew avoided exercise during activities like CFES which work better during low-acceleration periods.

The treadmill is an excellent exercise device and should be made a permanent part of Orbiter stowage.