Thornton

LIFE SCIENCES PAYLOAD
MISSION SIMULATION I

MISSION SPECIALIST REPORT

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CONTENTS

ABSTRACT

An identification and examination of the significant events occurring during the first Life Sciences Payload Mission Simulation, from conception on to the post-simulation reports, produced over 300 events possessing potential lessons concerning Space Shuttle/Spacelab requirements, designs, and operations.

A further analysis and interpretation of these lessons learned, considering experiences gained from previous spaceflight programs and existing Shuttle/Spacelab designs and operating plans, resulted in 127 specific recommendations to be developed and evaluated for implementation in the Shuttle/Spacelab Program.

This report is a presentation of those events, lessons learned, and recommendations and a brief discussion of the considerations and logic leading from perceived lessons learned and finally to a specific recommendation. The recommendations are numbered (R#) for future reference.

The recommendations concern training (R#1-34), Integration and Coordination (R#35-56), Flight Activities and Flight Control (R#57-84), Payload Hardware and Operations (R#85-101), Spacelab Requirements and Design (R#102-112), and Common Operational Research Equipment and Common Payload Support Equipment (R#113-127).

An index of all the topics addressed is included at the end of this report.

Of the 127 recommendations, 20 are specific for life sciences payloads while the remaining 107 are applicable to any Shuttle/Spacelab mission discipline.

These recommendations are neither directions nor policy. They are ideas and points of discussion: to be studied, developed, evaluated in future simulations, and supported, modified, or rejected. On the other hand, they are the result of lessons learned directly from experiences in a totally integrated simulation, patterned as nearly as practical, or possible, to the baselined designs and operations of the future Space Shuttle/Spacelab Program.

I. INTRODUCTION

This report is a documentation, compilation, and analysis of the significant aspects and events occurring during the development, training, and running phases of the first Life Sciences Payload Mission Simulation (LSPMS #1).

It is written with the perspective and point of view of a crewman and focuses on those aspects and events which I think provide lessons toward the conduct of subsequent simulations (sims) and the development and operation of the Shuttle-Spacelab program.

The report is derived from: 500 pages of crew debriefings (on file as an appendage to this report), 300 documentary crew photographs, and written and mental notes. The thoughts and analysis leading from perceived operation or event to the conclusion of a lesson learned and finally to a recommendation are, of necessity, presented incompletely in this report. More complete information may be obtained by referring to the detailed and extensive discussions in the crew debriefings (on file in the JSC Medical Archives, Building 37) or by calling the author, 713/483-2424.

While some of these recommendations, numbered (R#) for future reference, may not be the best way to go and some may not be practical or even feasible, they can serve as working options to be studied, tested, and, accepted, rejected, or modified. Recommendations concerning individual experiments (DTRs) and not applicable to either Spacelab design or operations are not presented here but have been passed on to the appropriate principal investigators and project engineers on a continuing basis. Those concerning; several experiments, experiments in general, or Spacelab design or operations are included in this report.

A DTR number appearing in the text in parenthesis, e.g. (DTR #9), is used to specify which experiments are applicable to or addressed by a given discussion.

II. SIMULATION PHILOSOPHY

LSPMS #1 has contributed to Shuttle-Spacelab thinking above and beyond it's stated objectives because it was patterned as nearly as practical, or possible, to the baselined operations of the future Shuttle-Spacelab program. The quantity and quality of the lessons learned and the validity of the recommendations obtained from a sim are directly proportional to the fidelity of the sim. LSPMS #1 possessed the best fidelity of any sim that I have worked and I attribute this to the test discipline and "mission spirit" of the operations team and to the real data generated by each experiment. The data served as the ultimate measure of crew, hardware, and system performance from early in the experiment development, through crew training, on to the completion of the sim.

While LSPMS #1 did not require the experiments to be qualified for zero-G operation, 6 of the 13 experiments were completely capable of operating in the zero-G environment in terms of component function, loose item restraints, fluid mechanics, and in running them we used zero-G operating and handling techniques. Another 6 experiments could be qualified for zero-G operation by the implementation of loose item restraints and fluid handling techniques well within the present state of the art.

III. TRAINING

A. Methods and Plans

The Mission Specialist (M.S.), Payload Specialist (P.S.), and some of the flight control team began experiment (DTR) training on 20 June 74, about 3 1/2 months prior to the start of this sim. In general, the M.S. and P.S. trained in parallel on all experiments and on all tasks. There were no Commander (CDR) or Pilot (PLT) crew members participating in this sim. Although it was occurring during this period, the division of labor between the crewmembers is discussed in the section of this report on integration and coordination. While I consider integrated sims to be the most valuable training mechanisms possible, they also are discussed in the section on integration and coordination because they serve those functions as well.

The over-the-shoulder training of key members of the flight control team simultaneously with the flight crew proved not only to be efficient but extremely beneficial to the development of; a team approach to the entire mission, procedures and check lists, and an optimum flight plan.

R#1: Key members of flight control teams should, on a non-interference basis, do some training simultaneously with the flight crews.

Training in Space Shuttle and Spacelab systems was not required for this payload simulation. The general approach to experiment training which evolved during the early weeks of training was:

1. Across-the-desk discussions with the P.I.s (principal investigators) on the scientific principles fundamental to their experiments.

2. P.I. briefings on experiment objectives, hardware, and operation.

3. P.I. demonstrations of experiment performance in the laboratory.

4. Crew performance of experiment in laboratory setting.

5. Crew performance of experiment positioned in spacelab racks both in the laboratory and in the Spacelab mock-up (DTU).

6. Crew participation in the integration tests of experiment - Spacelab interfaces.

7. Crew participation in integrated sims and "wet runs".

While specific aspects of this approach will be addressed later in this report, it was an efficient and effective method of training and at the same time was entirely compatible with the hardware flow in those experiments where actual flight hardware was used for training purposes.

<u>R#2:</u> Certain elements of this approach or the entire approach can be used for flight crew and flight controller training and to assist in the laboratory-to-flight integration process.

This training plan was not conceived prior to the start of training but evolved after several weeks of crew-principal investigator interaction and after several delayed and/or aborted runs. The real/time evolution of a training plan was a good way to go for this sim as one of it's purposes was to develop new ideas for use in a new program. While NASA possesses a tremendous amount of experience and capability in training toward spaceflight operations, the payload community is presently baselined with the responsibility for payload training.

R#3: NASA needs to develop a mechanism for passing on its expertise in spaceflight training to the payload community and be prepared to assist them at all levels of payload training.

The purpose of payload training is to prepare the crew to obtain the best possible data from the experiment in the spaceflight environment. The generation of real data by experiments during the training exercises (10 of 13 did during the training phases for this sim) greatly enhances the training process by: validation of procedures and checklists; providing immediate feedback to the operator; identifying areas for more or less emphasis; establishing a training objective or performance level; and by developing the interpretive abilities of the crew.

R#4: Where practical or feasible, payloads should generate real data during flight crew training.

R#5: For those payloads generating data in the training process, the training guidelines can define objectives in terms of data quality in addition to an elaboration of the subtasks to be accomplished.

Photography is a related area where this principle may be applied.

R#6: Photographic proficiency should be measured by the quality of the photographs taken by the flight crew in the simulator environment with flight-type cameras and flight-type film.

B. Payload Science and Operations

Most of these discussions concern the training of crewmen (M.S. or P.S. in this sim) on experiments for which they are not the principal investigators because, for this sim, there were 13 experiments (DTRs) and 20 principal investigators, one of which (P.S.) flew with his experiment. Because of the large numbers of experiments on life sciences dedicated missions, most experiments will be conducted by a crewman (CDR, PLT, MS, or PSs) other than the P.I., even if the baselined maximum number of P.I.s (4) are flown as payload specialists.

R#7: To enhance the quality of the experiment data the flight crew needs to be: not only technical experts in the experiments, but veritable extensions of the P.I. in the art of the science.

A strong rapport between the crew and P.I.s, both personal and professional, contributed much toward this end during this sim and could function in a similar way on future missions. This rapport and understanding and our observation of the P.I.s personal technique allowed us to mimic the art which they had developed with years of experience.

R#8: In cases where the P.I. is unavailable to participate in crew training, a representative of the P.I. or a NASA discipline-related scientist should be available to the crew.

In experiments such as DTR #4, adenovirus replication, consisting of many different sequential operations it is very beneficial to have some end to end training runs in addition to the subtask training. The P.I. and the crew would have liked to have scheduled that experiment for 4 hours for 7 consecutive days and have followed the same set of viruses and tissue cultures all the way through as in the flight situation.

R#9: For payload operations requiring many different sequential operations such as DTRs #4 and #8, training exercises should include some end-to-end runs with timing between elements as close as possible to the flight run.

R#10: End-to-end training runs of the above type can be useful in establishing the consummable requirements of payload operations.

Training with flight hardware, flight-type hardware or at least developmental-test-units is always advantageous over training with lower fidelity devices but this is particularly important in the learning of tasks involving art and "feel" or equipment with reproducible idiosyncrosies. An example of "feel" is provided by the SS20 (DTR #12), an important last minute addition, which we didn't see until the day prior to starting the sim. The operation was simply; note inject light, inject 1cc of blood, and push start. The SS20 developed an obstruction in its plumbing very early in its operation and we did not catch it because we did not have experience with the level of resistance that should be "felt" on the syringe during the injection.

As with all sophisticated machinery the majority of experiment hardware in this sim possessed several significant idiosyncrosies in operation but since, in every experiment, we trained on flight hardware we were bitten only once (light source on DTR #8 "GO" analyzer - "swing over, push down") and recovered the data in that case.

R#11: Flight crews should have a training experience operating flight or flight-type payloads or at least developmental-test-units of such when ever practical but especially where art and "feel" is involved in the operation or the hardware possesses significant reproducible idiosyncrosies in its operation.

In several experiments we had to highlight the critical operations or as we called them, the big No-No's, for ourselves.

R#12: In experiment training, as in all aspects of training, those operations which could lead to injury, hardware damage, or loss of data, should be highlighted in instructions, procedures, checklists, and reviewed frequently with the operator.

C. Payload Systems and Malfunctions

Many P.I.s had not expected to give us much or any systems training and some thought that we should not spend valuable training time on systems but should concentrate on operations. The payload systems training for this sim consisted entirely of probing questions directed at: the functions of all the controls; the interpretation of displays; component identification and familiarization, and a "walk through" of the plumbing and electrical circuits.

During the 7 days of simulation we explored the depths of 5 of the 13 experiments to diagnose, repair, or abandon several anomalies. In the sim debriefing, there was unanimous agreement among the P.I.s that the crew should have experiment systems training and an approach to malfunctions.

The philosophy toward experiment malfunctions in the Space Shuttle-Spacelab program is moving towards, "don't spend flight time trying to fix it, fix it at home, and fly it again". On the other side, the extensive history of Skylab experiment malfunctions shows that for many there were easy procedural work-arounds and for others, although they appeared catastrophic, there were simple fixes, e.g., a stuck micro-switch in a logic circuit. I think that Skylab history and our experience in this sim (DTR #1, 2, 6, 8, and 12) point toward some preparation and a reasonable effort to work-around or repair the inevitable inflight experiment malfunctions.

While the P.I. is frequently the person most knowledgeable in certain experiment hardware this was not always the case in this sim. Others included: the co P.I., the P.I.'s technician, the service representative, the manufacturer, the NASA project engineer, and the sim facility engineer.

R#13: NASA and the P.I. identify and designate for each experiment or for each major component where applicable, the person who is the systems or hardware expert on that experiment or experiment component.

R#14: NASA and the P.I. identify and obtain existing schematics for the experiment components.

R#15: The flight crew and pertinent flight controllers should receive basic training in experiment systems including: the functions of all controls, the mechanisms by which the control functions are accomplished, the source and interpretation of all displays including normal and redline operating limits, and a cursory simultaneous "walk through" of existing schematics and components.

R#16: Procedures development and training toward specific experiment malfunctions should be accomplished only for time critical failures and those identified as highly probable and not easily mastered inflight on a real/time uplink basis.

R#17: Additional training for payload malfunctions beyond the basic systems training (R#15) and a few specific procedures (R#16) should be broad in orientation and just sufficient to allow the flight crew to be extensions of the flight control team. Some examples of this general preparation might include: with assistance from schematics, diagrams, component photographs and flight controllers; obtain access to components, extend modules, replace modules with spares, locate and note positions of valves, locate bus terminals for multimeter testing, etc.

R#18: Provide some training, operations flow charts, and flight planned time to the crew toward occasional periodic observations and monitoring of experiment performance, particularly in those experiments which are primarily automatic in operation and in which the crew has little or no visibility into the data.

Design features which will facilitate the above considerations will be presented in the payload hardware section of this report.

D. Integrated Spacelab-Payload Training

The execution of some experiments (DTR #1, 3, 7, 9, 11, 12) changed very little as the experiment moved from laboratory configuration into the spacelab racks and finally into the spacelab mockup. The execution of others (DTR #2, 4, 8) changed significantly during this process requiring additional efforts toward integration and additional training to reacquire the same level of proficiency existant while the experiment was set up in the laboratory. The characteristics of DTRs #2, 4, and 8 responsible for this are: extensive storage, multiple loose items, several fluid handling requirements, many manual tasks, and multiple simultaneous and sequential operations.

R#19: The integration process and crew proficiency will be enhanced by getting complete exeriments into spacelab racks and into the appropriate spacelab mockup or simulator as early in the training period as possible.

Traditionally the flight crew have been the operators in the integrated testing of experiment flight hardware and the actual spacecraft. While the procedures used may not be identical to flight procedures as they are designed to test the experiment-spacecraft interfaces, participation in integrated testing may be the only opportunity for the crew to operate actual flight hardware in the environment of the actual spacecraft. In this sim, even though we had been training all along on the actual hardware, we welcomed the experience gained from 3 days of testing the experiment-spacelab mockup (DTU) interface and the data retrieval systems.

R#20: Where possible, the flight crew should continue to be the operators in payload-spacecraft integrated tests.

Mission training, as opposed to experiment or payload training, was accomplished during 4 days of integrated sims. These 4 days of integrated sims were identical to the 7 days of "flight" and included: experiment "wet runs" and real data, comprehensive flight plans, crew enclosed in mockup and on-their-own, all up flight control team, and hi-fidelity comm and data stream.

The contributions of integrated sims toward flight readiness other than training are discussed in the next section. Integrated sims provide training to flight crews, flight controllers, and experimenters above and beyond the payload training in many areas, including: real/time flight planning, adherence to time line, hardware malfunctions, communications, science priorities, launch to on-orbit storage reconfiguration, simultaneous experiment operation, division of labor, and housekeeping.

R#21: As in all previous space programs, integrated simulations are the best training experience available and they should be the apex of space shuttle-spacelab training.

R#22: Toward a 7 day life sciences dedicated mission, 4 days of integrated sims should be considered the minimum.

During the 3 1/2 month training period prior to the 7 day sim, I developed, at an exponential rate, a list of about 200 open items which needed resolution prior to flight. Most of these items were closed during unscheduled contact with the P.I.s in the spacelab (DTU) in days following integrated sims and immediately prior to the 7 day run. All the P.I.s were making final preparations with their experiments and were all available in the presence of the flight hardware and the integrated sims had pointed up any remaining problems.

R#23: Schedule 1 to 2 days of informal contact between P.I.s and the crew following integrated sims and in the integrated payload-spacelab or a spacelab simulator for the purpose of resolving open items prior to flight.

R#24: This period can also be used for last minute training (examples occurring during this sim: DTR #1 D.A.C. loads, DTR #3 inflight lignin data, DTR # 4, 5, and 10 TV microscopy, DTR #8 hematocruit andthe DTR #12 - SS20 operations) and training in carry-on experiments.

Hunting throughout a vehicle for a myriad of stowed items can tear up an extraordinary amount of spaceflight (experiment) time. During this 7 day sim we were proficient in the vehicle stowage as evidenced by: we never needed to refer to the stowage list, we never requested the ground for a stowed location, and we never lost anything. This proficiency can be attributed entirely to having a stowed spacecraft to physically review. Knowing where things are saves time to do science!

R#25: The only acceptable method for stowage training is the physical review of a hi-fidelity stowed spacecraft, simulator or "one g" mockup.

R#26: Photographic training should include taking photographs with flight-type cameras and flight-type film in the spacecraft or simulator environment and an examination and critique of the photographs prior to flight.

E. Overview

Prior to getting deep into the training period, the P.I.s requested a total of 115 hours of exposure time for crew experiment training. The eventual total came out to approximately 350 hours of exposure time including the 3 days of integrated testing and 4 days of integrated sims but not including developmental work, homework, and informal discussions and exercises. While the payload data, P.I.s, and flight directors are the appropriate judges of our proficiency and sim performance, I felt that the amount of training obtained and the resulting capabilities were optimum. I felt that we were still coming up to "flight speed" during the first 2 days of the actual run and yet we completed the flight plan and a few extra runs on those 2 days.

R#27: First-look training plans should reflect about 3 times as much training time as is requested by the P.I.s.

R#28: Three and one-half months including about 350 hours of exposure appears to be a reasonable estimate of experiment training time for a 7 day life sciences dedicated mission.

R#29: While we did not train on Space Shuttle-Spacelab systems for this sim, using experiences gained in training on Apollo-Skylab systems and being familiar with the preliminary designs for the Shuttle-Spacelab systems, I would estimate about 2 1/2 months and 250 exposure hours of training would be required in this area.

R#30: Six hundred hours of exposure time over a 6 month period appears to be a reasonable approximation of total training time required of the mission specialist and payload specialist(s) toward a 7 day life sciences dedicated mission.

R#31: I have reviewed the JSC/Flight Operations Directorate Spacelab Training Concepts as of February 1975 and consider them completely compatible with the lessons learned in this sim and recommend their implementation.

Included in these concepts are: a hi-fidelity spacelab "one g" mockup; spacelab simulator; and the capability for integrated orbiter-spacelab-payload simulations. As payload training is the responsibility of the payload people, their participation, including that of experiment hardware or simulators, is not defined. A spacelab simulation without the presence of experiment hardware or simulators would not be effective as a training or integration device.

R#32: Recommend payload participation, including experiment hardware or experiment simulators, in spacelab and orbiter-spacelab integrated sims. This is particularly important for those experiments which have extensive interfaces with spacelab systems, including CDMS, and orbiter systems, including GPC's and G and N functions.

R#33: Sims such as this one, the upcoming Life Sciences Mission Sim II, and foreseeable future Life Sciences sims, can serve as valuable training devices for crew, flight controllers, and P.I.s.

While the Life Sciences sims will probably never achieve the ultimate fidelity, such as CDMS control, monitoring and data handling of experiments and orbiter software interfaces, they do provide many of the essential elements of mission training and integration not provided by operation of individual experiments.

R#34: In order to evaluate and improve training concepts and techniques on a continuing basis, an analysis of the training accomplished and the resulting proficiency of the crew should be performed after each sim. It should include a detailed compilation of exposure hours to each phase of training (briefing, laboratory, spacelab-mockup, integrated tests, and all-up-sims) on each experiment and total exposure hours to experiments, tests, wet runs, sims, etc. It should also relate this exposure to proficiency levels attained as evaluated by the crew, flight directors, mission managers, P.I.s, and the data itself.

IV. INTEGRATION AND COORDINATION

A. Payload Management, Integration, and Coordination

One of the primary objectives of this sim was to exercise and evaluate the process of moving an experiment from the laboratory to flight readiness and to develop improved concepts for accomplishing this. Many of the lessons learned in this area are confirmations of Apollo and Skylab experiences. Several of the P.I.s had been P.I.s or Principal Coordinating Scientists (P.C.S.s) in the Skylab program and the ease with which their experiments moved down the line was proportional to their previous participation in the Skylab program.

R#35: P.I.s and payloads from institutions with little or no spaceflight experience provide a greater administrative and integrative challenge than those from spaceflight oriented groups and they should be included as frequently as possible in future sims to facilitate the development of our laboratory to flight processes.

R#36: NASA has extensive experience and expertise in developing and flying scientific payloads and experiments and needs an effective and reproducible mechanism for passing this knowledge on to future P.I.s and payload organizations.

R#37: NASA develop a "user's guide" which not only addresses required documents, experiment constraints, and spacecraft interface specifications, but a detailed blow-by-blow description of the operational elements occurring from lab to landing.

R#38: As in Apollo and Skylab, the early assignment of a project engineer and astronaut or scientist astronaut to each flight experiment and early communications between them and the experiment group assists in the technical and operational integration of the experiment.

R#39: The P.I.s for each experiment should provide a brief written description of their experiment, including the scientific fundamentals, methods, hardware, data and objectives, for the early education of the crew, project engineers, flight controllers and the P.I.s of other experiments assigned to the same mission.

For this sim, the only available information on the experiments prior to the start of training was a two page summary. I would have been far better prepared for the early P.I.-crew sessions had I read a brief such as R#39 or a few reprints concerning ground based runs of the experiments.

In life sciences dedicated missions or in missions having several experiments in related disciplines, the scientific return can be greatly increased by not only correlating the data between experiments but by running common protocols involving several experiments. In this sim a gas chromatogram (DTR #6) was planned to be run on the atmosphere of the pine chamber (DTR #3) and on a real time basis a microbiological study (DTR #11) was performed on a DTR #2) dog. The potential for multiple significant experiment interchanges existed in this sim and was not used to advantage. One example could have been the correlation of hematological (DTR #8), biochemical (DTR#12), and physiological (DTR #2) data in the same subject.

R#40: P.I.s assigned to common missions can greatly increase the scientific return of that mission by learning the data potential (R#39) on all other discipline related experiments and developing common protocols for data correlation.

R#41: P.I.s assigned to common missions and having similar hardware requirements not met by mission CORE (common operational research equipment) or CPSE (common payload support equipment) can share the development and inflight use of the same experiment hardware.

R#42: Protocols involving several experiments (R#40), the correlation of data from several experiments utilizing the same subjects, the sharing of experiment hardware (R#41), the mission specificity of part of the CORE and CPSE, the utilization of specific discipline-trained crew and flight controllers, and the single-shift operation favored by life sciences experimentation, (R#57), support flying life sciences payloads on life sciences dedicated missions as opposed to spreading them out among many multidisciplinary missions. While "piggy-back" and "carry-on" flight opportunities should not be passed up by life sciences studies, for the above considerations, I recommend grouping the major life sciences flight opportunities into dedicated missions.

R#43: While this life sciences dedicated mission sim pointed up the advantages of the discipline dedicated mission (R#42), we need to conduct a multidisciplinary mission sim to evaluate to what extent we lose those advantages and to identify the advantages and problems associated with the multidisciplinary mission.

R#44: The installation and removal of experiments into and out of spacecraft racks, the movement of these loaded racks into and out of the spacelab, crew training on "wet" experiments, simultaneous training on several experiments, integrated sims, and wet runs of hardware cannot simply be scheduled but need to be coordinated with all operational elements, particularly the P.I.s and payload organizations.

Inherent to the life sciences payloads are living organisms whose birth, development, biochemistry, physiology, and flight readiness cannot be time-compressed. The P.I.s participating in this sim made an extraordinary effort to provide living payloads in the appropriate biological stage (DTR #2, 3, 4, 5, 10, 11) for the required exercises and this effort contributed significantly to all aspects of the sim.

R#45: Sophisticated multiorganism vivariums (DTR # 2, 3, 4, 5. 10, 11) are required at life science payload integration and launch centers to serve as holding and staging facilities between laboratories and the integrated spacelab or launch vehicle.

R#46: While it is the responsibility of the payload organization to deliver their payloads to the integration or launch facility on schedule, NASA should establish several intermediate milestones in the development of each payload, assess their progress, identify the schedule problems, provide technical assistance where necessary, and have an alternate mission plan when it becomes impossible for some of that mission's payload to meet the critical milestones.

The above suggestions (R#46) appear so obvious as to not need inclusion in this report but they are here because, during the week prior to the start of this sim, we were training every night from 6:00 p.m. to 10:00 p.m. to acquire minimum proficiency on a late arriving experiment which had not received the early coordination efforts and technical power that it needed.

R#47: A mission manager could serve as a focal point for: the management, integration, and coordination of payloads; the implementation of R# 36, 37, 38, 40, 41, 44, 46; and the overall attainment of mission objectives.

B. Flight Crew Integration

The flight crew for this sim consisted of a mission specialist (astronaut, clinical surgeon, and physiologist) and a payload specialist (molecular biologist and pharmacologist). The commander (CDR) and pilot (PLT) positions were accounted for on paper (flight plan and timeline analyses) but did not participate in this sim.

R#48: As the CDR and PLT are integral members of all space shuttle and Shuttle-Spacelab crews and will have considerable time and ability to perform payload operations, their participation should be incorporated in future sims.

The ability of pilot and scientist astronauts to conduct spaceflight experiments has been established in previous programs, particularly the Apollo and Skylab programs. Present timeline analyses indicate that for a life sciences mission the CDR and PLT would have approximately 16 hours of total time each spaceflight day to dedicate to payload operations.

R#49: Baseline operations plans should reflect payload operations by the CDR and PLT to the extent that they are available from orbiter and spacelab systems operations.

The perception of expertise and the division of labor on the experiment operations between the mission specialist (M.S.) and the payload specialist (P.S.) evolved during the team approach to experiment integration and training. Working with and training on the experiments as a team demonstrated very clearly each crewman's capabilities on each experiment and on the subtasks within each experiment operation. These capabilities were evident to the crew, the P.I.s and the flight controllers. This process accounted for and integrated crewman: education, scientific experience, personality, motivation, training, and other factors, in a way impossible by an arbitary designation of payload responsibilities. The lesson learned here was "Football coaches should not assign team responsibilities until they have met the players."

R#50: The allocation of payload operations between flight crew members should be based, in part, on experience derived from their working and training together as a team.

While specific consideration must be given to: the individual team members, the payloads, the mission, the experiences gained from team work and team training, and other factors, several general recommendations on allocation of payload tasks came out of this sim.

R#51: The CDR and PLT can serve as operators or observers in many life sciences experiments (DTR # 1, 3, 6, 7, 9, 11, 12, 13).

R#52: The CDR and PLT can serve as subjects in life sciences experiments (DTRS # 1, 7, 8, 9, 11, 12, 13).

R#53: The CDR and PLT can work life sciences experiments' malfunctions (DTRS #1, 6, 12, 13).

R#54: Contrary to the present baseline, the CDR and PLT should not perform payload housekeeping unless trained as operators on that payload.

R#55: In multidisciplinary missions and multiple payload missions the M.S. should be responsible for the operation and attainment of objectives of some of the payloads.

R#56: As payload specialists will possess widely different scientific interests and operational capabilities, their participation in payloads not their own and not within their discipline of interest should be determined by individual motivations and the flight team integration process addressed in R#50.

V. FLIGHT ACTIVITIES AND FLIGHT CONTROL

A. Flight Plan, Timeline, and Performance

R#57: While two-shift days are baselined for Shuttle-Spacelab operations, a single-shift 16 hour day, such as run on this sim, is advantageous for life sciences dedicated missions because of the significant effect of circadian shifts on biological data and the need for sleep (DTR#2) or dark periods (DTR#3) by the biological subjects.

R#58: Although a single-shift 16 hour day is recommended for life sciences missions, future sims should exercise the problems and advantages associated with the two-shift day.

R#59: "Living in" or the confinement of the flight crew within the spacecraft for the entire mission simulation was extremely important toward making valid evaluations of: the flight plan, mission timelines, crew performance, and the ability of the crew to cope with the totality of habitability and payload problems arising during the 7 day sim.

A length of 7 days was used for this sim because 7 days was, and is, the baselined length of minimal length life sciences dedicated missions.

R#60: Considering the lessons learned during this sim,and when in the sim the learning took place, 7 days appears to be an adequate time to identify the greatest majority of events which lead to recommendations. Even to shake-down 14 day and 30 day life sciences missions, I think 7 day sims will do the job. On the short side I don't recommend less than 5 days for this type of shake-down sim.

R#61: As was done in this sim, the basic daily flight plan should be constructed by the flight activities officers on the ground because they are: the world's best flight planners; aware of payload operating constraints; experts on payload timelines; familiar with frequency requirements and can incorporate the miltiple changes requested by all the payload organizations as real/time spaceflight data revises the scientific priorities. An exception to this recommendation would be the mission flying only one or two payloads and a P.I. for each payload.

In that case it would probably be advantageous to move all the flight planning upstairs.

R#62: During this sim we accomplished a significant amount of real/time onboard flight planning by: dovetailing additional experiment runs of our choice into the basic flight plan (DTRs #1, 3 inflight lignin study, 6, 7, 8 hematocrit, 8 chemistry rotor, 11, 12); dovetailing malfunction procedures into the basic plan (DTRs # 1, 2, 5, 8, 12); swapping tasks between crewmen; compressing meal times; compressing housekeeping and personal hygiene times; and by extending the times dedicated to the "art of science" (DTR # 4, 5, 6, 8, 10). This onboard modification of the flight plan to enhance the scientific return of the mission worked extremely well.

To do this form of real/time onboard flight planning, the crewman needs to be ahead of, or at least even with, the basic flight plan and have additional time to put on extra runs, malfunctions, or the art of the science. We bought additional time by working an average of 18 hours a day and stole additional time from eat periods, personal hygiene periods, "leisure time" periods, and physical training.

R#63: Real/time onboard flight planning requires that the crewman possess free time to be used on tasks at this discretion. The basic daily flight plan should contain blocks of "crew option" time and enough pad in the scheduled timelines to allow for onboard decisions on the use of time.

R#64: Although I have recommended that the basic daily flight plan be originated on the ground (R#61), we should exercise total onboard flight planning during 2-3 days of the next sim by giving the M.S. responsibility for construction and implementation of the flight plan.

B. Flight Activities and Procedures

R#65: Written flight procedures are essential not only as checklist for payload performance but as: a learning tool in the identification of tasks and an outline of the approach; a discrete baseline to be critiqued and improved; an agreement and understanding of how the payload is being operated; a source of payload communications and terminology; and an elaboration of the critical points (R#12) in payload operation.

During the 7 day "flight" period of this sim, we rarely, and for some experiments never, referred to the written flight procedures because we had them to study and use and massage for several weeks prior to going to run.

R#66: Although NASA has a tremendous accumulation of experience and expertise in building flight payload procedures, the payload organizations will have this responsibility in the future. NASA (JSC Flight

Operations Directorate) needs to develop the mechanism for passing on this experience and expertise to the payload people or for sharing with them the responsibility for flight procedures development.

We had a useable and firm set of flight procedures prior to the 2 days of all up sims and 2 days of experiment "wet runs" but the sims and "wet runs" produced changes in 100 pages of the total of 150 pages of flight procedures. This fact is further support for my contention that the training for and conduct of a mission are not simple summations of those activities for individual payloads.

R#67: Integrated simulations are the best instrument for the final shaping and verification of flight procedures.

R#68: Having a single flight procedures book for each experiment, as opposed to grouping the procedures for several experiments into one book, was highly beneficial to the simultaneous operating of several experiments and to the process of real/time inflight updating and is recommended for spacelab module operations involving multiple experiments.

R#69: Payload systems schematics, as pointed up in R#14, should be included as part of the flight data file.

Supported in part by the fact that we did not utilize all of the controls and displays on several of the experiments, the flight procedures for this sim did not include (as in all previous space programs) an on-orbit initial verification of the entirety of controls for a given experiment prior to it's operation.

R#70: Although this philosophy bit us only twice (in small ways - crew time only) during this sim, the foreseeable prelaunch payload closeout procedures, the launch accelerations and vibrations, and the small penalty of crew time necessary, favor doing a total controls and displays verification on each payload prior to proceeding with it's operation.

Although there was no formal photographic plan for this sim: we had excellent photographic training (briefings and practice with flight-type camera and film); possessed a camera and adequate film; and took about 300 documentary photographs during the 7 day sim period. These photographs have been extremely useful, not only in recording the events of the sim, but in the documentation of many of the lessons learned presented in this report.

R#71: Provide abundant film for "targets of opportunity" and, with the exception of data photographs requiring a specific format and technique, leave format and technique to the crew, i.e., tell them what you want and let them do it.

Recommendations on photographic capability and hardware are addressed in the section on CORE and CPSE.

While we had one hour/day flight planned for physical training (exercise), I preferred to devote this time to running experiments and working on malfunctions.

R#72: For the: 7 day mission provide exercise hardware but don't include exercise periods in the flight plan; 7 to 14 day mission leave the flight planning of exercise up to crew option; and for missions longer than 14 days include exercise periods in the flight plan.

We took 7 hours sleep the first night and gradually reduced the sleep to 4 hours on the last night. This was the result of commitment to getting the most out of a 7 day mission and probably reflects the sleep patterns which might exist on an actual mission.

R#73: Although some of it will probably be used as "crew option time" on a seven day mission, continue to flight plan 8 hours of sleep/night.

R#74: "Off Duty Activity Equipment" such as provided on Skylab is not necessary on 7 day missions.

C. Flight Control and Ground Support

From the crewmen's point of view, the flight control and ground support elements of this sim were, without exception, superb. Many of those people had gained experience in similar positions during the

Apollo and Skylab programs and this experience was abundantly evident in their performance.

R#75: Another factor of great importance was that through working together in the developmental stages and training together on the experiments and in the simulations and "wet runs" the flight crew and the ground crew had been integrated into a single, personal, empathetic operations team.

The general trend, in moving from the Apollo-Skylab programs to the Shuttle-Spacelab programs, is to place many responsibilities, traditionally performed on the ground, onboard the Shuttle-Spacelab resulting in a more vehicle autonomous operation than in the past. Most of the thinking and documents on payload operations assume the P.I. or his representative will fly with each experiment. For a life sciences dedicated mission, I estimate a composition of 20 experiments and 30 P.I.s, only 2-3 of which are flying with their experiments.

R#76: While in this sim, and certainly as would be the case for an actual flight, we were capable and confident of performing the nominal payload operations without any assistance from the ground, I am certain that the quality of the science was tremendously enhanced by the running collaboration between the crew and the P.I.s through real/time voice, video, and data communication.

R#77: The P.I.s or their representatives and the payload hardware experts addressed in R#13 should be available in the Payloads Operations Control Center (POCC) or through a telephone patch into the POCC during missions.

This crew - P.I. collaboration was particularly important in those experiments involving complex crew tasks and considerable art and scientific judgement (DTR # 2,4,5,6,8,9.10).

R#78: The baselined concept of two air-to-ground communications channels (orbiter and payload) will strongly support the above crew-P.I. collaboration.

R#79: Real/time collaboration during payload operations requires an umbilical or wireless headset for VOX or "hot mike" communications similar to that used during EREP passes on Skylab. Speakerbox-press-to-talk communications will severely restrict air-to-ground communications during payload operations.

R#80: The 78 minutes of ground contact (aquisition of signal) during each 90 minute orbit that we used on this sim assumes perfect performance of the time-data relay satellite system (TDRSS) and an ideal attitude for AOS of the orbiter. Subsequent sims should utilize less than optimal and varying AOS-LOS times.

R#81: Payloads operations which are greatly improved by AOS (DTR # 4, 8, 9) and those which require AOS (DTR #2) should be identified early, flight planned accordingly, and coordinated with other operations such as to fit into AOS intervals.

While the Mission Operations Planning System (MOPS) computer terminal, which we used for flight planning and flight procedures development and display, was not intended to represent the design or identical function of either the Shuttle General Purpose Computer (GPC) or the Spacelab Command and Data Management System (CDMS), it did provide a meaningful mission related crew-computer-ground interraction and at least a few lessons.

R#82: Onboard hard copy capability is very useful and a time saver in updating the flight data file including flight plans and flight procedures.

R#83: Computer design and software should provide the operator a method for extracting himself from logic loops and dead-end streets and get back to where he entered the program or in Apollo-Skylab language, get back to P00.

In previous programs, the capsule communicator (capcom) served as the principal point of voice contact between the flight crew and the ground. This was advantageous because the capcom was an astronaut who: had worked and trained for years with the flight crew; was familiar with the flight crew; was familiar with the science, hardware, and flight procedures, and knew and understood a particular crewman's approach to the mission and specific tasks.

The controllers occupying the "PLANS" position in this sim (in function, the Flight Activities Officer) were excellent "capcoms" because they had worked and trained with the flight crew and were intimately familiar with the payload operations and the overall mission because they were responsible for the construction of the flight procedures and the flight plan.

R#84: The "Science Manager" within the POCC is baselined as the principal point of voice contact for payload operations. Extensive exposure to: the crew, the entirety of the payload package, flight procedures, and the overall mission will assist him in carrying on where previous "capcoms" left off.

VI. PAYLOAD HARDWARE AND OPERATIONS

As stated in the introduction, this report does not address the lessons learned and subsequent recommendations for particular individual experiments but only those which apply to several experiments or payloads in general. Suggestions concerning particular experiments have been passed on to the P.I.s and P.E.s on a continuing basis.

R#85: Payload scientific data should be available to the flight crew at the payload station or displayed through the CDMS. This will enhance the quality of the data by: providing feedback to the operator and improving his performance; identifying below par or malfunctioning operations; and by allowing for real/time scientific judgement and the pursuit of "targets of opportunity" (DTRs #1, 2, 3, 4, 5, 6, 7, 8, 9, 10).

R#86: Provide visibility by the crew into appropriate payload components for the observation and verification of: nominal operations (DTRs # 1, 3, 6, 8, 12, 13); diagnostic procedures (DTRs # 3, 6, 8, WBC counter, 12, 13) and as a continual vivid presentation of the payload systems to the operator (DTRs # 1, 3, 6, 8, 12, 13).

R#87: Provide crew access to payload components and modules for: unplanned hardware modifications (DTR #6); malfunction analysis and repairs (DTRs # 1, 2, 6, 8, 12, 13); and changeout with spares (DTRs # 1, 8, 12).

R#88: Complex payloads with automatic functions, logic circuitry, and limited operational visibility (DTR # 13) should possess status indicators such as lights or flags to provide the operator a means of following the logic sequence. Tweaking a single microswitch may be the difference between nominal operations and total failure.

R#89: Color-coding and labeling of: components; vacuum, gas, and liquid lines; wires; buses; etc. will: help guarantee correct interfaces to GSE (ground servicing equipment) and to the spacecraft; assist in the learning and understanding of the systems; and would be essential to malfunction diagnostics and fixes (DTR # 1, 2, 3, 6, 8, 12, 13).

R#90: Where multiple samples are to be processed in parallel lines, (DTRs # 4, 8, 12) color code: the samples (chambers, test tubes, syringes, bags); the process (reagents, syringes, cuvettes, counting chambers); and the stowage locations at all stages of the process.

R#91: Design out procedural errors (DTR #1, Mass Spectrometer Valves), while if possible, maintaining operational flexibility.

R#92: Many experiments cannot be conveniently and routinely run from their launch stowage configuration (DTRs # 2, 4, 5, 8, 12) and a very significant reduction in the crew timeline can be achieved by developing and implementing an on-orbit operational stowage and restraint system to be used repetitively in the day-to-day experiment operation.

R#93: During the experiment training we identified or developed little tools-of-the-trade for individual experiments or groups of experiments which helped us to get the job done (DTRs #1, cue cards; 6 textbook; 8 white blood cell illustrations; 10 fish egg embryology photos; etc.), and we need a mechanism for getting these items into experiment stowage.

R#94: Where consummables could be the limiting factors on the number of experiment runs (DTRs #, 5 film; 6 AVCs; 8 stain; 8 rotors; 11 chips; 12 tubes and syringes), include considerably more of these items than is called for on the flight plan.

R#95: Provide covers for all optics (DTRs # 4, 5, 8, 10) when they are not in use.

R#96: Several strip-chart recorders (DTRs # 4, 6, 8, 9) ran uncontrolled paper out into the spacecraft. In some cases (DTRs # 4, 8) there isn't a lot of paper and you may want to label it and cut it up right way. In others (DTRs # 6, 9) there is a lot of paper which requires time to roll it up and it will be all over the spacecraft in 0 "g". The latter should have automatic take-up reels such as the one on DTR #2.

R#97: While 0 "g" design, restraints, and operational techniques were not required for this sim, these considerations should be introduced in subsequent sims at a rate to have us completely 0 "g" by the sim prior to the first spacelab flight.

We had enough extra space in the drawers and racks (DTRs # 3, 4, 5, 10, 11, 12) that I estimate about 20 experiments could have been flown as opposed to the 13 which were.

R#98: In future sims or missions where space only is the payload limiting factor, assign partial racks and drawers to individual experiments instead of the entire compliment of single or double rack.

Life Sciences as well as other disciplines are significantly impacting spacelab systems during the launch and entry phases of the mission in areas of: late prelaunch and early post landing access; launch and entry, power, environmental control, and biotelemetry.

R#99: Study the feasibility of carrying biological subjects (i.e., dogs, monkeys, plants, etc.) in special transport cases mounted in the orbiter racks. These could be loaded and unloaded with the crew eliminating the access problems. They would use orbiter environment without special provisions and visual contact by the M.S. or P. S. would replace the biotelemetry.

R#100: Study the feasibility of using the spacelab core segment laminar flow workbench for handling and preparing biological subjects and samples. There is adequate light, class 10,000 clean air, and restraint is provided by the air flow.

R#101: In the Shuttle-Spacelab missions, the capabilities of man should be utilized to provide biological subjects (DTRs # 2, 3), including plants and animals, a physiological and psychological environment far more comfortable and closer to that which they are accustomed than can be accomplished by the automatic biosatellite. These efforts will help to guarantee that the observed physiology and biochemistry are a result of the spaceflight environment, including 0 "g", and not a result of circumstances associated with the experiment.

VII. SPACELAB

Construction of our spacelab module mock-up began even prior to the final selection of the Spacelab contractor so it did not represent an exact replica of the baselined design. The payload, of necessity, did not interface with common spacelab subsystems but with GSE (ground support equipment) located external to the mock-up and maintained by facility engineers. We did not monitor and control spacelab and payload systems and a central data stream through the CDMS (command and data management system). These limitations, while not seriously effecting the contributions of this sim to training, payload integration, flight planning, flight control, and payload design concepts, do require that contributions to spacelab design be a result of extrapolation rather than the application of direct experience.

R#102: Control of the payload-to-spacelab interfaces, including vacuum, gas, and fluid lines, electrical power, and data lines should be on the spacelab side of the interface and controllable by the crew.

If this control (valves, connections, switches, etc.) is on the payload side of the interface, spacecraft reliability and quality will need to be imposed on a multiplicity of individual payloads rather than on one spacecraft. As an example, if an individual payload develops a leak in its vacuum system, we should have the capability of closing a valve in the vacuum line going to that payload.

R#103: The payload compliment flown in this sim can be used to determine the: electrical power; heat rejection; space; waste management; vacuum; water; and inert gas requirements of a typical life sciences dedicated mission where the payloads have been taken directly from the laboratory and not modified significantly for spaceflight.

R#104: For the same considerations as in R#103, each experiment participating in subsequent sims should be weighed.

R#105: Conversely, subsequent sims will occur after the spacelab specifications requirements review (SRR), and a payload compliment can be selected which will operate within the power, heat rejection, weight, etc., capabilities of the baselined spacelab.

Much of the spacelab design is presently based on the assumption that the CDR and PLT will remain in the orbiter at all times while it is very likely that the majority of their time in a life sciences dedicated mission will be spent in the spacelab module (R# 49, 50, 51, 52, 53).

R#106: Spacelab environmental control system (ECS) design and its interface and interaction with the orbiter ECS should include the occasional addition of CDR and PLT metabolic loads to the spacelab module rather than the orbiter.

R#107: Orbiter initiated caution and warning (C+W) tones in addition to Spacelab C+W tones should be routed to the Spacelab module and a light in the module should indicate that the orbiter is the source of the C+W.

R#108: The orbiter air-to-ground communications loop should be available from the spacelab module.

R#109: The design of the Spacelab ECS should not require the hatches between the orbiter and the Spacelab to be closed during nominal operations.

R#110: The Spacelab racks should provide: access to the experiment modules (R#87) and to the experiment-to-spacelab interface; experiment visibility (R#86); flexibility in on-orbit stowage and restraint provisions (R#92) and facility in on orbit experiment installation and removal as would be required in transferring experiments between the orbiter and Spacelab and spares changeout.

R#111: Spacelab lights should be individually controllable and of variable intensity (DTRs # 3,4,5,7,8,10).

R#112: Electrical power requirements analysis for specific missions should plan for some payloads (DTRs #1, 6, 7, 11, 12) to be powered up continually, not just when in operation.

VIII. CORE, CPSE, AND TOOLS

CORE (common operational research equipment), CPSE (common payload support equipment), and tools will be developed and provided by different organizations for the Orbiter, Spacelab Module, life sciences dedicated missions, and for specific life sciences missions.

This report identifies tools, instruments, and capabilities which were, or could have been, useful in the execution of this life sciences dedicated mission but it does not attempt to classify them as to CORE, CPSE, or tools or to suggest which element of the Shuttle-Spacelab system should develop and provide a specific item. Items such as microscope, 37° incubators, refrigerators, and freezers which are already generally accepted CORE items for life sciences missions are not addressed.

R#113: Video downlink was extremely useful in working malfunctions (DTRs #1, 6, 12) and supporting P.I. participation in the mission (DTRs # 2, 3, 4, 5, 6, 8, 10).

R#114: Color capability would have significantly enhanced the value of the video downlink (DTRs # 2, 3, 4, 5, 8, 10).

R#115: A universal mount similar to those used in Skylab is needed to position the video camera on racks, grids, handholds, etc.

R#116: Ground command of the video camera in the Spacelab will result in considerably more useful video downlink and will save flight crew time.

R#117: An electrical multimeter was an essential instrument in many diagnostic procedures (DTRs # 1, 2, 6, 12, 13).

R#118: A diagnostic oscilloscope would extend the capabilities of the multimeter in R#117.

R#119: Soldering iron and 0 "g" soldering technique (DTR #2).

R#120: Zero "g" fluid containment, manipulation, and transfer capability (DTRs # 2, 3, 4, 5, 6, 8, 10, 11, 12, 13).

R#121: A "vacuum cleaner" with liquid retrieval capability to clean up spills occurring in the experiments addressed above in R#120.

R#122: Automated collection, measurement, and sampling of biological waste including urine and feces. DTR #13 appeared to be an excellent approach to handling urine and could be pursued to perfection.

R#123: Centrifuge for the separation of biological samples (DTRs # 8, 12).

R#124: Inflight animal holding and handling facilities (DTR #2).

R#125: Radioisotope holding, handling, and control facilities and techniques (DTR #2).

R#126: Turret-type oculars can provide simultaneous microscopic viewing, photography, and video downlink.

R#127: Still and motion picture photographic capability including hand-held, microscopic, and oscilloscopic applications. Each system should possess an internal photometer and/or automatic shutter. Lens extension tubs are frequently needed for the close-up photography of biological specimens.

IX. CONSPECTUS

The above recommendations are neither directions nor policy. They are ideas to be studied, evaluated in future sims, and supported, modified, or rejected.

On the other hand, they are the result of lessons learned directly from experiences in a totally integrated simulation of a life sciences dedicated Spacelab mission. Simulations of this type have been and continue to be, the final and most valuable integration, training, and verification exercise for flight crews, controllers, and procedures.

X. INDEX OF TOPICS ADDRESSED

TRAINING

Flight Activities and Procedures

Flight Control and Ground Support

PAYLOAD HARDWARE AND OPERATIONS

SPACELAB

CORE, CPSE, AND TOOLS