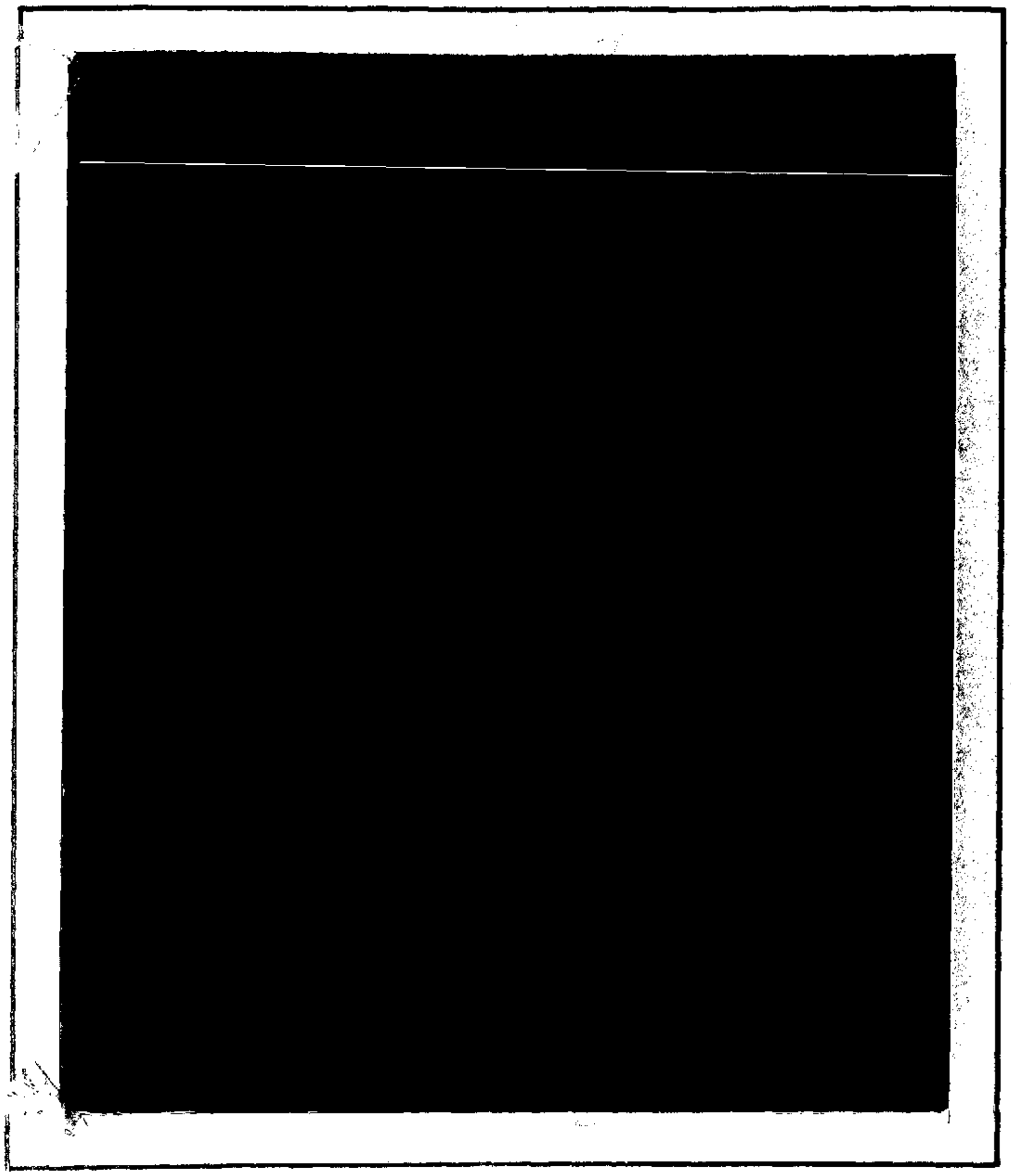

(NASA-CR-120398) ROLE OF MAN IN FLIGHT EXPERIMENT PAYLOADS, PHASE 1 (Essex Corp.) 68 p HC CSCL 05E

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ROLE OF MAN IN FLIGHT EXPERIMENT PAYLOADS - PHASE I

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SUMMARY

The effort described in the present report was directed toward development of a technique for quantitatively determining role of man requirements for Spacelab missions. The role of man was operationally defined as the allocation of necessary experiment functions to crew members. The set of functions to be performed by a particular scientific crew member then defines his role.

To meet the objectives of the effort, a generalized Spacelab experiment operational sequence was developed and the parameters necessary to describe each single function in the sequence were identified. Since a review of currently available payload planning data showed that the necessary detailed data were not available, a set of functional descriptor worksheets were developed. The methodological approach to defining the role of man was defined as a series of trade studies using a digital simulation technique. The trade-off variables identified include scientific crew size, skill mix, and location. An existing digital simulation program suitable for the required analyses was identified and obtained.

The phase of the effort reported here thus served to identify the required data for studies of Spacelab experiment functional allocation, develop an approach to collecting these data from the payload community, and to specify the analytical methods necessary to quantitatively determine the role of man in specific Spacelab experiments.

Conclusions and results of the present study include the following:

Conclusions:

- The operational definition for determination of the role of man in Spacelab experiments is a trade-off approach based on the effectiveness of alternative allocations of functions to crew members.

- The data necessary to perform trade studies in the area of role of man are the detailed functional requirements for specific experiments.

- The detailed functional requirements data are not provided in the presently available payload data summaries.

Results:

- The detailed functional data for exercise of the methodology were defined in the current study and appropriate worksheets have been developed.

- The next step in the effort to define the role of man should be the collection of detailed functional requirements data from payload planners, Spacelab simulation efforts, and manned spaceflight experience. To accomplish this, the crew skills method of Ref. 2 were incorporated into the SSPD effort during the course of the study.

- Where possible, the conduct of Spacelab simulation efforts should be structured to provide the data identified as necessary for the role of man determination.

- Based on suitable input data, the methodology developed during the current study can provide the performance data for trade studies in the role of man approach defined above.

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1.0 INTRODUCTION

The Space Shuttle is curently planned as a logical continuation of the increasing capability of NASA to support scientific experimentation in space. Throughout the Demini, Apollo, and Skylab programs, the trend has been toward greater allocation of resources to science and applications experiments. The Shuttle system represents a further step in this trend in that it will meet the flexibility and low-cost criteria necessary to orbit experimental payloads and scientific personnel from a wide range of disciplines.

1.1 General Background

The Shuttle Orbiter will reach near earth orbit, remain on orbit for the mission duration (7 to 30 days) and will land as does a conventional aircraft. The orbiter payload for Spacelab missions will consist of the Pressurized Module and/or the Pallet system contained in the Orbiter payload bay. The Pressurized Module provides an orbiting laboratory in which the scientific crew works in a shirt-sleeve environment. The Pallet permits the exposure of experiment components (such as telescopes) to the space environment.

The combination of Pressurized Module and Pallet provides for flexibility of experiment accommodations. Depending on objectives and requirements of various disciplines, the Spacelab is envisioned as operating in any of several modes including:

- Module only - The Spacelab consists of several modules providing a large working area. The experimental apparatus is installed in the Module allowing several investigators to work much as they would in an earth-based laboratory.
- Pallet only - Where experiment requirements dictate exposed apparatus, the system may consist of only the Pallet. Control of the experimental apparatus may then be exercised from the Orbiter or from the ground.

- Pressurized Module plus Pallet - Where large exposed apparatus and a pressurized laboratory area are required, the Pallet together with a minimal Pressurized Module may be provided. Since the Spacelab is modular, the laboratory volume may be traded for Pallet capability if required by a particular experiment.

These modes will provide the flexibility for a wide range of experiment payloads since crew size, hardware mass, and other parameters may be traded as considered necessary for various experiments.

The approach to meeting the criterion of low cost includes provision for rapid modular installation and changeout of experimental apparatus in the Module or on the Pallet and minimum training and preparation time for the scientific crew. These features are necessary to meet the objectives of the scientific community. Flexibility of operational mode, ability of the scientist to fly his experiment with minimum flight training and mission preparation, and low cost per experiment have been cited as factors in the success of the Ames Airborne Science Program (ref. 1).

The effort being reported here is based on the conflict of the above objectives in certain areas. The capability of a particular Spacelab experiment payload to return data of sufficient quantity and quality to meet the experiment goals will depend heavily on the performance of the scientific crew. The degree of this dependence will be expected to vary between disciplines. Certain experiments in the Space Processing area are currently envisioned as being highly automated and sequenced with little necessity for modification of later experiments based on prior results and only minor crew requirements at the technician level. Astronomy missions, on the other hand, are planned to permit flexibility and selectivity in terms of sources observed. In this connection, Skylab experience has shown the utility of man's ability to make unscheduled observations - such as the data collected on solar flares. Many of the planned Spacelab missions rely on this demonstrated capability to re-orient the observational effort toward phenomena of opportunity. Closely related to this selectivity in terms of source observed is the topic of data filtering and data compression. These data gathering modes utilize the human's capability to select, reject, and reduce data in real time to increase the quality of the resulting data while reducing the magnitude of recording requirements.

The conflict in meeting the stated objectives is due to at least four factors:

- Dependence of data return on scientific crew capability and performance
- The highly specialized nature of the equipment employed and of the resulting man-machine interactions
- The requirement for minimum training and pre-flight preparation on the part of the scientific crew
- The tendnecy which is evident in the payload planning data toward reduction of scientific crew size to obtain increased weight for instruments and experimental apparatus

The result of these factors is that as crew size is reduced to accommodate more apparatus, the functional requirements placed on the crew remain constant or even increase. Thus, the decrease in the available manning level results in a quantitatively greater workload per crew member. Equally or perhaps more importantly, the variety of functional operations may increase resulting in a requirement for diverse skills on the part of the reduced crew complement. This problem would be accontuated when multi-discipline payloads or carry-on experiments are considered. Therefore, the requirement that the skill and manning levels of the scientific crew be commensurate with the functional requirements of the mission is in conflict with the objective of accommodating a wide range of scientific personnel while minimizing the training and preparation time necessary for the scientist to fly his experiment. The trend toward greater diversity of skills per crew member leads to either stringent personnel selection criteria, or extensive cross-training or both. This skill diversity problem is further accentuated by the fact that skill definition methods used in the past by NASA have tended to suggest greater homogeneity of skills within disciplines than actually exists.

The probelm may be summarized by noting that Spacelab experiments will entail the operation of specialized equipment by specialized individuals and the adequacy of the obtained data will depend on the capabilities of the crew members to meet the information processing, decision, and action requirements of the experiment in question. The skill requirements thus generated will be complicated by the need for multi-discipline missions where the existing within-discipline skill diversity will be augmented by between-discipline requirements.

1.2 Assessment of Problem

The tendency toward reduced scientific crew size increases the need for cross-specialty crew skills. This results in severe constraints on the number of individuals with the variety of skills necessary to fly, and increased time for cross-training both within and between disciplines. At present, no methodology exists for assessing the impact on mission objectives of reduced scientific crew size, constrained skill diversity, and crew member workload. Where such impacts exist, the options exist of allocating experiment functions to automated equipment or to ground-based personnel. Such approaches would generate problems in operational flexibility, system cost and complexity, and up and down link information transmission rates.

The alternative approaches to meeting the functional requirements of a particular Spacelab experiment which were considered in the present study include:

- Principal Investigator on board - The scientist who conceives and designs the experiment flies on the shuttle and operates the experiment.

- Experimenter/Technician on board - An experimenter trained in the operation of the experiment flies on the shuttle and operates the experiment.

- Experiment control from the ground - The experimental equipment is monitored and controlled from the ground via the Shuttle up- and down-links.

- Experiment automation - The experiment is designed to operate automatically without operator actions - possibly being simply turned on and off by the Shuttle flight crew.

The first mode, in which the PI flies his own experiment, is a logical continuation of the methods employed by the Ames Research Center Airborne Science Program (Ref. 1). This mode offers the greatest degree of flexibility in terms of experiment modification and response to phenomena of opportunity. The primary problem that arises is that the PI is likely to be a highly specialized individual and may be unable to participate in cross-training necessary to operate experiments other than his own. This approach will thus be useful primarily for single discipline and perhaps single experiment payloads.

The second approach involves a research assistant or experimenter. Such an individual would presumably be a specialist in the operational aspects of experiment conduct and would have a general understanding of the purpose and principles of the experiment although he would not need to have a detailed knowledge of the underlying theory. The experimenter role has been fully defined in a previous Essex effort (Ref. 2). This approach might also involve a technician who would be differentiated from the experimenter role by a reduced level of scientific skills but an increased ability to perform hardware calibration, checkout, and repair.

The second mode offers somewhat reduced flexibility in terms of modifying the experiment or responding to phenomena of opportunity. This could be partially offset if the PI were in voice contact with the experimenter or technician during experiment conduct. The advantage of the second approach is that the individuals on board the Shuttle could presumably be cross-trained and thus able to operate numerous experiments in the course of one mission.

The third mode obviously reduces weight which is payload chargeable since it involves remote control from the ground. The feasibility of this mode depends on the type of information needed by the operator to adequately perform the experiment and on the up-link command data which the operator transmits. The question of accommodation via this mode involves a comparison of Shuttle communication system capacity with the information requirements of the experiment. The problem of coverage also arises. Use of the remote control mode for real time experiment operation would appear to rest on the availability of the Tracking Data Relay Satellite System (TDRSS) in terms of coverage. A problem area, given deployment of TDRSS, however, would be transmission lag. Studies of orbital teleoperator control systems show these lags to result from ground line transmission and to involve variable delays on the order of several seconds. The ability of a human operator to perform continuous control (such as sensor pointing) functions with this lag duration in the system is questionable (Ref. 3).

The fourth mode, automated experiment operation, avoids the weight penalty for an on-board operator and the problem of closed loop ground control. Flexibility, however, would be lost and the increases in experiment hardware cost and complexity would impact the availability of low cost benefits to the user population.

The present study represents an attempt to provide an analytic methodology for performing trade studies in the area of scientific crew composition, location (ground or on-orbit), and skill mix. This approach involves analysis of the functional requirements of particular Spacelab experiments and a technique for projecting scientific crew performance in meeting experiment objectives as a function of the crew parameters listed above. Such a technique can then be employed to permit quantitative trade studies in the areas of:

- Spacelab experiment hardware design
- Operational procedures & mission planning
- Scientific crew composition

The present study was directed toward development of a methodology which permits quantitative study of functional allocation to the on-orbit crew, to the ground, or to automated equipment in terms of impacts on realization of mission objectives. Since the capability of the human observer has been termed the most important resource of the Spacelab program, the present effort provides an approach to optimal allocation of this resource - in much the same fashion as do trade studies being performed of other resource constraints such as power and mass.

2.0 OBJECTIVES AND APPROACH

The study being reported here is a follow-on to a prior Essex effort (Ref. 2) which was performed under contract NASW-2389. The primary outputs from that effort were:

- A summarization of human resources requirements on the part of Spacelab users - primarily the Payload Planning Groups
- A generalized flow diagram for Spacelab experiments
- A matrix method for classifying and describing the role of man in Spacelab missions based on the discipline involved, the level of scientific skills and the level of technical skills

2.1 Study Objectives

The objectives of the present study were to update and revise the role of man definitions based on updated user requirements data (Ref. 4) and to provide a method for utilizing the role description methodology to specify the role of man in specific payloads. A further objective was to provide a method for the communication of detailed functional requirements from Spacelab users to Spacelab designers. The functional requirements method described in this report was developed to permit scientific crew trade studies and to support refinement of the role definition technique based on updated functional requirements data.

2.2 Approach

The approach employed in the present study is illustrated in Figure 1 which describes the analytical technique being developed. The operations depicted in Figure 2-1 show the end product methodology rather than the exact flow of the effort although the two are closely related. The input data to the illustrated methodology describes the experiment in question at three levels of detail:

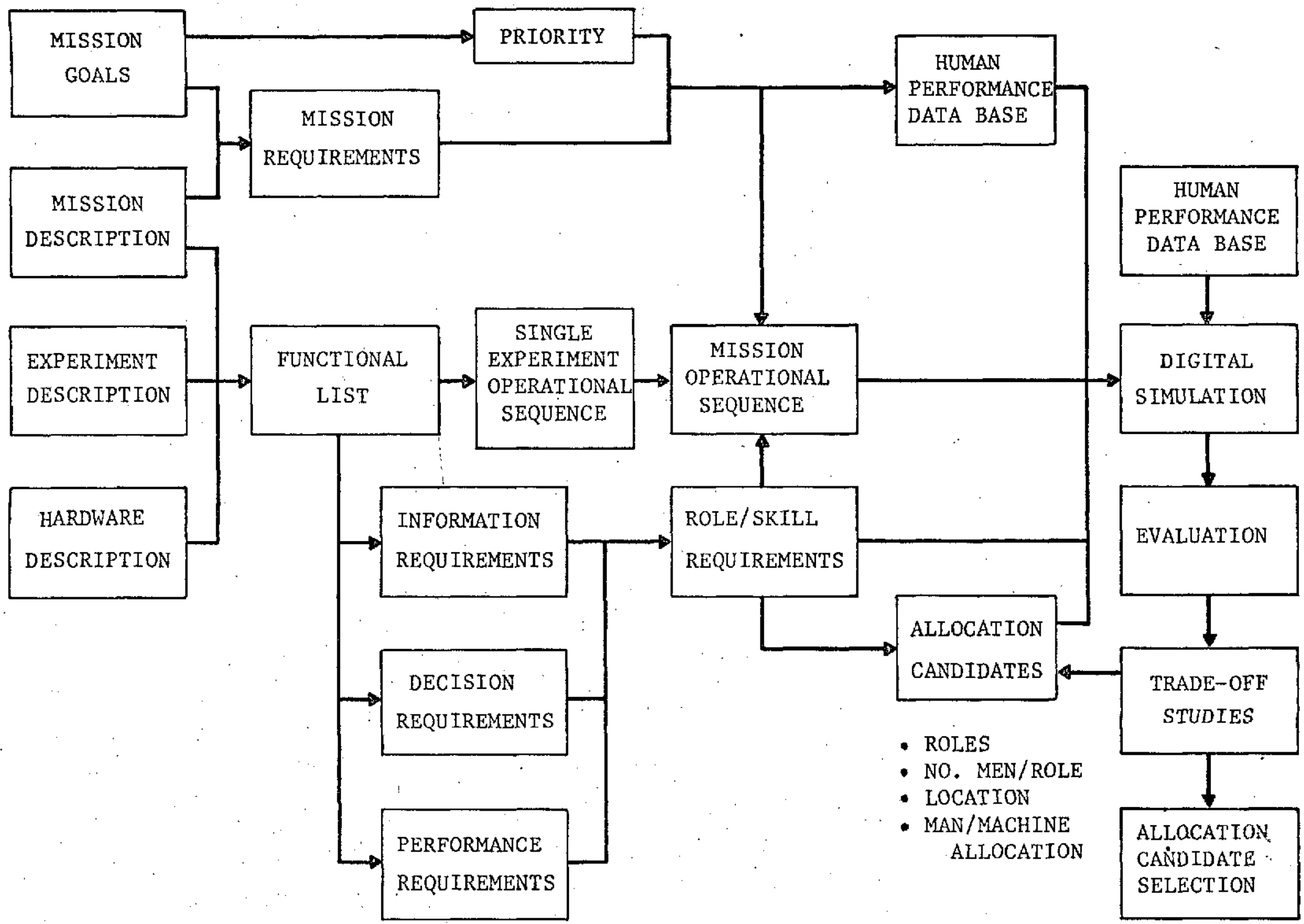

FIGURE 2-1. FLOW OF ROLE OF MAN METHODOLOGY

* Mission level - including orbital parameters, the nominal observation timeline based on opportunities for conduct of the experiment, and constraints due to other experiments in the experiment

* Experiment level - including the individual experiment hardware and procedures.

* Function level - describing the sequence of functions or tasks to be carried out by the scientific crew in performing the experiment

These data would be integrated to produce a mission operational sequence diagram detailing functions to be performed in the conduct of the experiments comprising the mission. The functional input data would describe the nature of each function in the sequence in terms of:

* Branching relationships with other functions

* Information, decision, and action requirements of the function

* Resource utilization statistics for the function - particularly time to complete the function and the skill mix and number of crew men involved

These parameters reflect the process of determining the role of man in a particular experiment as discussed in Ref. 2. The parameter values for the functions in a particular experiment would be either fixed by the nature of the experiment or would be free to vary. In the latter case, a trade-off methodology, as discussed in connection with the section on objectives, would be applied to determine the values of the free parameters so as to maximize the likelihood of realizing the goals of the experiment.

The application of the tradeoff methodology would require evaluation of function allocation candidates. A functional allocation for a particular experiment would specify the number and skills of the members of the scientific crew and would assign each function of the experiment to one or more crew members (including those on the ground) or to automated equipment. The current approach to evaluating allocation candidates is to employ an existing digital simulation program described in a later section to exercise the operational sequence and thus produce statistical data on experiment completion time, operator load, and likelihood of experiment completion within the time available for the experiment as determined from the nominal mission timeline. The approach thus has the following properties:

- The basic inputs to the determination of the role of man in a particular experiment are data on the functional requirements of the experiment.

- For each function identified, data on the parameters of the function are either available from the payload planner or are free to vary. Defining the role of man consists of fixing the variable parameters soas to maximize the likelihood of realizing the mission objectives.

- The selection of values for variable parameters will be based on a digital simulation program which exercises the experiment operational sequence under constraints introduced by various candidate allocations of the required functions.

- Exercising this methodology will satisfy the objectives of the effort since it will yield quantitative evaluation of effects of both hardware design and procedural or mission planning decisions on the performance capability of the scientific crew.

The approach being employed stresses the <u>functional requirements</u> of Spacelab experiments. The application of the methodology under development depends on availability of detailed data on the functions which must be completed to perform the experiment in question. Consequently, the current phase of the effort was devoted to determining the degree to which the necessary functional requirements and function parameter data are being made available to Spacelab designers via the various payload requirements data collection efforts presently being performed. A technique for obtaining these detailed data from mission planners was developed, and preparation of the digital simulation program for use in exercising operational sequence networks was carried out. Effort was also devoted to updating and expanding the generalized experiment flow network originally developed in a previous phase of the effort (Ref. 2). This updated sequence diagram serves as a framework for the functional requirement data collection effort and serves to define requirements for the digital simulation program.

3.0 REVIEW OF CURRENT FUNCTIONAL REQUIREMENTS DATA

To determine the degree to which detailed experiment functional requirements data are available, existing documentation bearing on crew functions and experiment operations was reviewed. This included:

- General Crew Function Data
  - documentation produced by the payload planning groups including the 1973 Woodshole Conference (Ref. 5)
  - documentation on generalized crew functions developed in the course of Spacelab design studies such as the April, 1974 Crew Functions workshop held at JSC (Ref. 6)
- Experiment Specific Crew Function Data
  - payload descriptions such as the SSPD level B data sheets (Ref. 4) and the NASA ESRO payload summaries (Ref. 7)
  - crew function data developed in the course of payload accommodation studies such as Refs. 8, 9, 10, and 11

3.1 Evaluation of Present Functional Requirements Data

In general, the documentation reviewed was not found to provide the level of detail with respect to functional requirements necessary for the present study. Conversations with persons involved in payload planning efforts, however, suggested that such data would be available from the payload community if systematically requested.

Several areas may be noted in which functional requirements data were identified which are not available at the present time.

3.1.1 - Level of Description

The greatest level of detail noted in the review across a wide range of disciplines and objectives was available from the SSPD (Ref. 4) level B payload descriptions. Even where specific payload design or accomodation studies have been undertaken, this level of detail was seldom exceeded. The crew operations described in the SSPD level B sheets generally deal with crew functions as:

- Experiment deployment and set-up
- Experiment operation
- Experiment termination and stowage

As will be discussed in a later section, this level of detail corresponds to a first-level flow for a single experiment. For the purposes of the present investigation, however, description of second-level flow for experiments is required. The need for this type of data prompted the development of a generalized second order operational sequence diagram as part of the present effort. These second-level specific functions are required for any man-machine allocation, activity, or control/display analyses to be performed in the course of Spacelab experiment hardware design. The course of man-machine system design which proceeds from system objectives, to operational analyses, to hardware design requirements would not appear to obtain a firm basis from mission analyses which proceed only to the available level of detail.

3.1.2 - Crew Time Requirements

Closely related to the question of level of description is that of function completion time. The capability of performing valid crew size, allocation, and crew skill analyses rests on the availability of required and obtained function duration data. In this context, crew time is viewed as a resource as are power, fuel, etc. Power and mass allocation for the Shuttle System have been analyzed to some degree of exactness but the ability to study the allocation of the crew time resource is gross in comparison.

It is necessary to distinguish between available and obtained time with respect to the duration of some experiment function. Available time here refers to the nominal experiment timeline. In certain disciplines, the viewing time for a particular celestial object or earth feature will be constrained by Shuttle/Spacelab design features and by the parameters of the orbit. Such constraints are external to the present effort since a variety of nominal timeline planning methodologies exist (Refs. 12, 13). The present effort addresses obtained time which is that required for a scientific crew of a certain size, having certain skills, following certain procedures, and using certain equipment to successfully complete the experiment in question. Realization of the goals of the experiment requires largely that required time and available time coincide. Since required time depends on human performance, it will be a statistical quantity. The impact of this fact is discussed in Appendix I.

The time requirement data generally available appear to deal largely with available time. Activity charts for the SSPD level B data sheets (Ref. 4) show first-order crew activities with associated blocks of time. These durations are generally estimates obtained from scientists who are familiar with the operations in question. Generally, these operational blocks of time fit into the available time for the repetitive cycle of the experiment. This method implies that these time periods are additive. While it appears obvious that the time for a sequence of operations equals the sum of the single operation times, this approach involves many difficulties as is shown in Appendix I.

Whether the given operation times represent average, maximum, or some other measure of obtained performance time is not made particularly clear in the available data. The nature of these estimates taken as formal statistics has a considerable impact on the likelihood that the operation in question will be completed within the available time. The variability of the time required for an observer or team of observers to complete an experimental operation is not explicitly treated in the available data.

A second time-related problem deals with the operator loading for a particular operation. It is difficult to determine from the currently available data whether the operations in question are sequential, in which case addition of times would be appropriate within the constraints discussed in Appendix I, or parallel, in which case a single observer could be carrying out two functions during the same period of time. This uncertainty makes analysis of man loading difficult. A tabulation of man-loading requirements for Pallet only missions carried out during the present effort yielded ambiguous conclusions due to uncertainty about parallel vs. sequential operations.

Currently, the information available on pallet-only missions was not found to permit the types of analyses discussed in the current report. The data presented here represent an attempt to compare user requested on-orbit crew size with function performance times taken from the level B timelines. The results are shown in Table 3-1 which contains requirements for manloadings and derived manloadings. The first column of Table 1 shows user requested manloadings as given in the pallet-only level A sheets of September 13, 1973 (Ref. 7). These figures are manloadings - number of men on duty during a shift - not total crew size. It is assumed that 12 hour shifts are employed. Column 2 shows corresponding figures for the April, 1973 user's requirements (Ref. 14) documents. Of the available data, one mission - AS-07-5 - was reduced from 2 men to 1. The next 5 columns contain data from the October, 1973 Level B Data Sheets (Ref. 4). Column 3 gives required manloading based on Ref. 4. Column 4 contains the sum of times to complete all tasks during

TABLE 3-1. PALLET-ONLY MISSIONS - MAN LOADINGS

		1 LEVEL 1 SEPT. 1973 CREW SIZE @ 12 HR/DAY	2 APR. 73 USER RQTS	3 CREW SIZE	4 MAN HRS./ OBSERVATION PERIOD	5 OBSERVATION PERIOD HRS.	6 M.L. PER.
AS-01-S	1.5 COOLED IR TELESCOPE	1	1	1	1.89-2.27	1.55	1.22-1.47
AS-03-S	DEEP SKY SURVEY TELESCOPE	1	1	1	1.50	1.50	1.00
AS-04-S	1 M. DIFF. LIM UV TELESCOPE	1	1	1	1.50	1.50	1.00
AS-05-S	VERY WIDE FIELD GAL. CAM.	1	N.A.	1	1.50	1.50	1.00
AS-06-S	ASTR. FLUX CALIB.	1	N.A.	N.A.	N.A.	N.A.	N.A.
AS-07-S	COMETARY SIMULATION	1	2	1	.747	.727	1.028
AS-08-S	MULTI PURPOSE .5M TELESCOPE	1	N.A.	N.A.	N.A.	N.A.	N.A.
AS-09-S	30 M. IR INTERFEROMETER	1	N.A.	1	1.85	1.55	1.19
AS-10-S	XUV TELESCOPE	1	1	N.A.	N.A.	N.A.	N.A.
AS-11-S	POLARIMETRIC EXPERIMENTS	1	N.A.	N.A.	N.A.	N.A.	N.A.
AS-12-S	METEOROID SIMULATION	1	1	N.A.	N.A.	N.A.	N.A.
AS-13-S	SOLAR VARIATION PHOT.	1	N.A.	N.A.	N.A.	N.A.	N.A.
AS-14-S	1 M UNCOOLED IR TELESCOPE	1	N.A.	N.A.	N.A.	N.A.	N.A.
AS-15-S	3 M AMBIENT IR TELESCOPE	1	N.A.	N.A.	2.04	1.55	1.32
AS-18-S	1.5 KM IR INTERFEROMETER	2	N.A.	2	1.85	1.55	1.19
AS-19-S	DEEP SKY SURVEY	1	1	N.A.	N.A.	N.A.	N.A.
AS-20-S	2.5 M CRYO-COOLED IR SCOPE	1	N.A.	1	2.17	1.55	1.40
HE-02-S	X-RAY IMAGING STUDIES	1	1	1	1.80	1.50	1.20
HE-05-S	COSMIC RAY	1	N.A.	2	4.50	1.50	3.00
HE-06-S	X-RAY/GAMMA RAY SURVEY	1	N.A.	2	7.50	1.50	5.00
LS-04-S	TELEOPERATOR	2	N.A.	2	1.63	1.63	1.00
SO-01-S	DEDICATED SOLAR SORTIE	2	N.A.	4			
SO-10-S	HIGH ENGY SOLAR PHYS	1	N.A.	N.A.	N.A.	N.A.	N.A.
ST-08-S	INT. R.T. CONTAM MON.	0	N.A.	0			
ST-08-S	CONTROLLED CONTAM. REL.	0	N.A.	0			
ST-12-S	ENTRY TECH.	1	N.A.	N.A.	N.A.	N.A.	N.A.

a typical experiment cycle based on the Level B timelines. These data are in terms of man hours. Column 5 shows the total elapsed time for one cycle. Column 6 shows the ratio of man hours to elapsed hours which is a derived man-loading estimate. Comparisons of derived man loadings with requested duty crew size gives an estimate of the need for additional crew members.

Among the astronomy missions some overload is indicated in 5 of the missions for which derived estimates are available. Assuming that this introduces the need for a second operator in the loop, the question of location arises. The present analysis does not discriminate between the Minimal Pressurized Module and the payload specialist station approach. In both cases, required information both in terms of support and scientific data would be available in real time. The Level B and Level A sheets (Refs. 4, 7), however, generally assume that the excess workload will be carried by ground based personnel. This approach increases the data transmission requirements if a ground based crew member must receive support or scientific data and issue up link commands.

One obvious problem is that communications tracking is lost during a portion of the orbit with the currently available tracking network. A timeline analysis of an IR astronomy mission performed by Northrop Services, Inc. (Ref. 12) yielded over 130 hours of observation using two IR telescopes. Without relay satellites, however, the total track time during the 7 day mission was approximately 76 hours. Even assuming that observations can be scheduled during tracking periods, this places constraints on the sources that can be observed.

A common requirement across astronomy missions is fine pointing of the telescope. This function is assumed to be automated via use of a star tracker system in the Level B data sheets. The experience of the Ames Research Center Airborne Astronomy effort, however, casts some doubt on this method. According to practicing astronomers there, automated pointing is not an entirely satisfactory mode. They dedicate a man full time to monitoring the guide telescope field of view via TV and controlling pointing in a manual mode. Their experence has been that observation requires constant adjustment of pointing to meet experiment objectives. The astronomer monitors sensor returns and instructs the technician to alter the pointing in various ways including moving off the source to record from the background. To the extent that this is also required in shuttle astronomy missions, it adds a full time or one man function to the operation and such a function is not included in Level B data sheets (Ref. 4). This is an example of detailed functional information which is required but not yet available. If this function were allocated to the ground personnel, transmission lags in the data acquisition system would seriously degrade performance in controlling fine telescope pointing.

The currently available data for astronomy missions suggest some problems in functional allocation. The tradeoff is increased mass if the on-orbit crew is increased in size versus information transmission complexity and possible performance decrements if additional functions are allocated to the ground. The functional analysis suggested earlier should be implemented during the concept development effort to provide quantitative data for resolution of these problems.

3.2 - Current Status of Crew Requirements Definition

The SSPD level B data sheets (Ref. 4) on each candidate Spacelab payload report estimates of crew requirements in terms of number, skill designation, and hours required by skill for experiment setup, operation, and termination. To date the skill designations used in SSPD data sheets have comprised the list of 23 skills described in the prior Essex study (Ref. 2). As indicated in that report, the primary problems associated with the use of this list for identifying crew skill requirements are:

- The list does not provide for different levels of skill.
- It does not include all of the skills required for different Spacelab payloads.
- It reflects different levels of emphasis for different disciplines.

It was based on a recognition of these problems in skill definition that the matrix of skill requirements was developed in the prior Essex study (Ref. 2). This matrix provides for differentiation of skills along three dimensions, level of scientific skill, level of technical skill, and discipline area. Three general crew roles are included in the matrix (see figure 3-1) which are investigator, experimenter, and technician.

During the current study Essex personnel have discussed the matrix approach to skill designation with individuals responsible for the SSPD data sheets (Ref 4). The result of these discussions is that the data sheet updates, currently in preparation, will use the Essex designations for crew skills and skill levels for all payloads.

In order to describe the current approach toward crew requirements definition the Advanced Technology Lab payload 1 being defined by personnel of the Langley Research Center was selected. The ATL represents probably

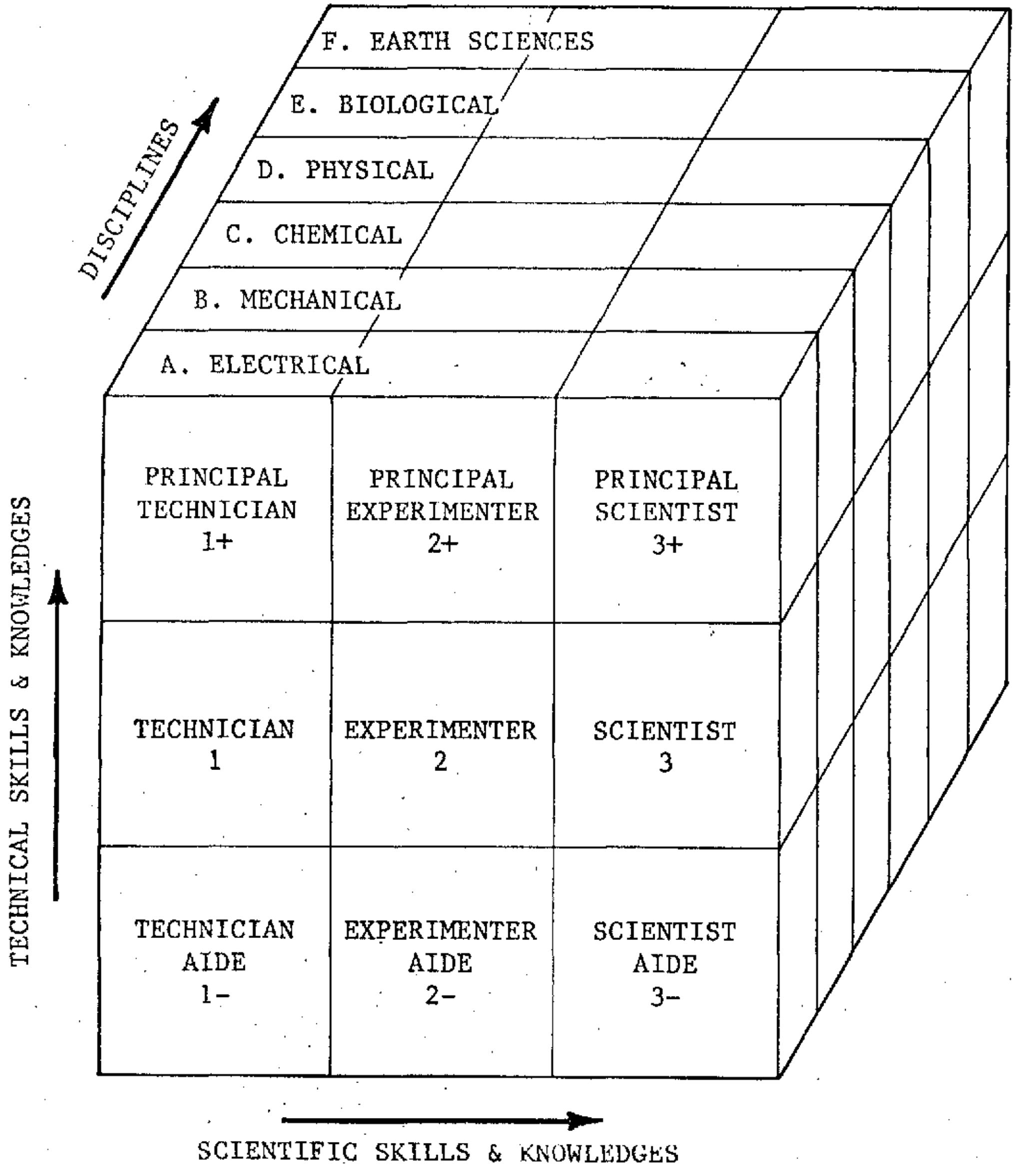

FIGURE 3-1. ROLE OF MAN CLASSIFICATION SCHEME

the most advanced spacelab payload in terms of state of requirements definition. The laboratory itself incorporates a 20 foot long pressurized module and a 20 foot pallet. An extensive listing of candidate experiments for the ATL have been identified and are described in ref. 13. Based on discussions with ATL personnel at Langley it was determined that the packaging of experiments into candidate payloads had been updated from the information reported in the ATL description (Ref. 13). The candidate experiments for payload 1 (described as the most representative payload in terms of crew requirements) and the crew requirements associated with these experiments are listed in Table 3-2.

As indicated in this table a total of five different skill designations were identified over the 13 different experiments (electronic/optical technician, electronic/optical scientist, microwave electronic technician, microbiologist, and any). The baseline ATL requires a crew of two, therefore some combination of skills within each crew member will be required.

The total man hours required for the setup, operation, and termination of the experiments is 106.4. Of these, 13.58 are relegated to set up activities during the first mission day, and 5.33 are identified as termination activities during the final (seventh) day. Therefore 98.15 man hours are required for experiment operation over the 5 day on-orbit, and 19.63 hours are required per day for each of the five on-orbit days. This results in 9.87 hours of experiment operation per crewman per day.

The scheduling of crew time is such that functions are classified as experimental and nonexperimental. Experimental functions include setup, operation, and termination of experiments. Nonexperimental functions include:

- medical checks
- personal hygiene
- preparation of meals and dining

TABLE 3-2 CREW REQUIREMENTS FOR ATL PAYLOAD 1

					Crew Time				
	Experiment	No. Crewmen	Skill	Man Hrs	Initial Setup	Hrs/Day Operation		Term.	Targets
NV-1	Microwave Interterm.	1	ET	22.5	.5	2-8 1	ops calibr.	1	world
NV-2	Autonomous NAV	1	Electronic/ optical scientist	35.3	3	.5 1 4-5	monitor comm control	.5	world-star
EO-7/8	Search & Rescue/Imag. Radar	1	Microwave ET	17.0	1.5	5	control	1	world
EO-1	Lidar Measure	1	Elec/opt. technician	8.0	2	1	control	1	clouds
PH-6	Meteor Spectroscopy	1	Elec/opt. technician	4.5	2	.3	control	1	NA
MB-1	Colony Growth	1	Any	.5	.25	0		.25	NA
MB-2	Transfer of Microorganism	All	Any	7	--	7		--	NA
MB-4	Elec. Character. of Cells	1	Microbio.	6.75	4	2.5		.25	NA
MB-5	Special Properties of Cells	1	Microbio.	4	--	4		--	NA
CS-2	Steam Generator	1	Any	--	--	2		--	NA
EN-1	Airborne Particles	1	Any	.33	.08	.16		.08	NA
EN-3	Nonmetallic Material	1	Any	.5	.25	--		.25	NA
	External Contamination	None	--	--	--	--		--	NA
				106.4					

- ATL system housekeeping
- mission planning
- sleep (8 hours per day, two men simultaneous)

One potential problem for ATL operation is the frequency and duration of communication contrast between the orbiting ATL and the STDN gound statistics. The average time over any site was about 7 minutes and the average number of passes over all sites was about four per day. The average total contact time with the ground was 6 hours per day or 25 percent of total on-orbit time (ref. 13). Without the almost 100 percent contact afforded by use of TDRSS, it will be difficult to implement in the ATL the recommendations/requirements generated at the Crew Functions/Payload Operation Workshop (ref. 6). One specific requirement which applies to Spacelab-ground interfaces is that new or modified procedures should be entered into the computer primarily from the ground and that changes or updates of command sequences should come from the ground. With the ATL operating on STDN there will be periods of up to two hours where contact with the ground will not be possible. This constraint must be taken into consideration when assessing the allocation of crew skills to the on-orbit ATL or to the ground.

4.0 GENERAL CREW FUNCTIONS APPROACH

4.1 - Generalized Experiment Flow

This section describes the conceptual approach, developed in the course of the study, to the problem of collection of the detailed functional requirements discussed in Section 3.0. The initial point of departure was considered to be a generalized functional flow diagram for Spacelab experiment operations. Such a diagram was developed in connection with a previous study (Ref. 2). The current effort was devoted to updating the initial flow based on revised payload data from the SSPD effort (Ref. 4), payload accomodation studies (Refs. 6, 8, 9, 10, 11, 12) and discussions with Payload planners.

The current effort which deals with crew operations is closely related to the hardware items being utilized by the crew. At the general level of crew functions which cut across disciplines and missions, a generalized description or taxonomy of equipment based on functional characteristics was employed. For this purpose, the activities involved in Spacelab experiment operations were viewed as a series of information transmissions within the system. The flow of information is shown in Figure 4-1.

The labels for the various system elements of Figure 4-1 are defined below:

Experiment Hardware Categories

- Sensor - The class of elements which receive energy directly from the environment.
- Transducer - The class of elements which recode sensor outputs into electrical or other signals suitable for transmission within the system.

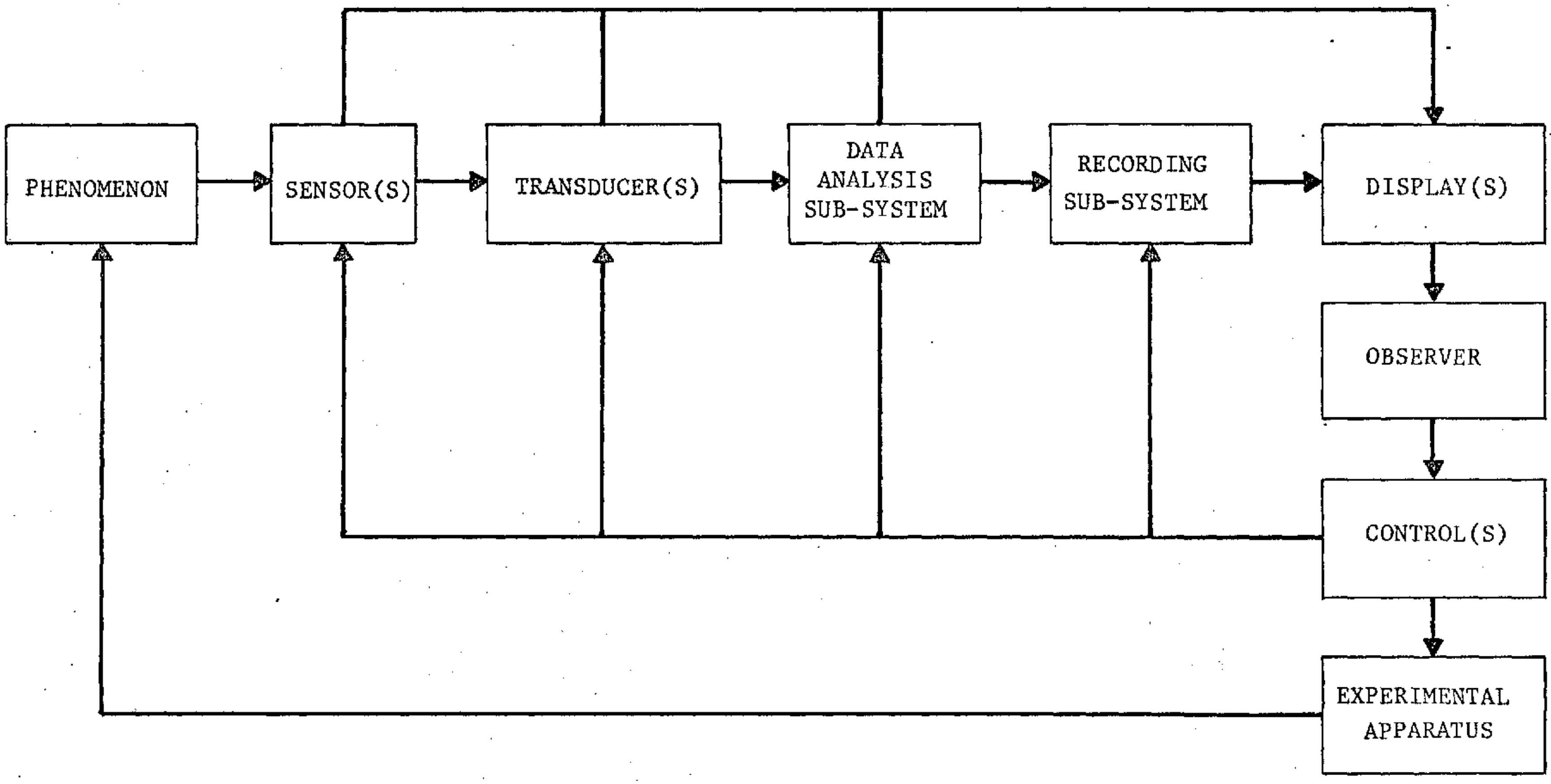

FIGURE 4-1. SPACELAB EXPERIMENT INFORMATION FLOW

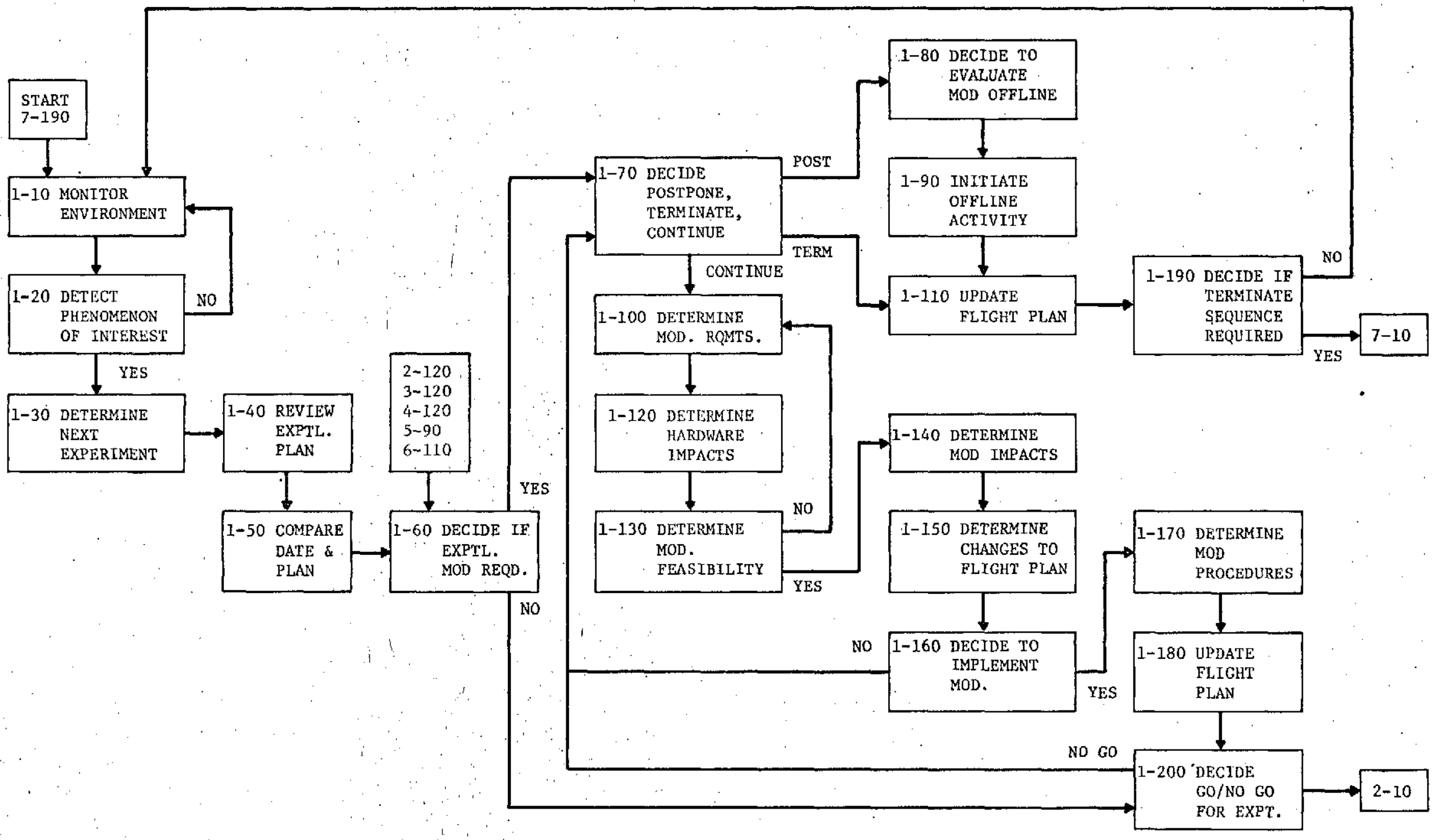

FIGURE 4-2. PHASE 1 - EXPERIMENT SELECTION

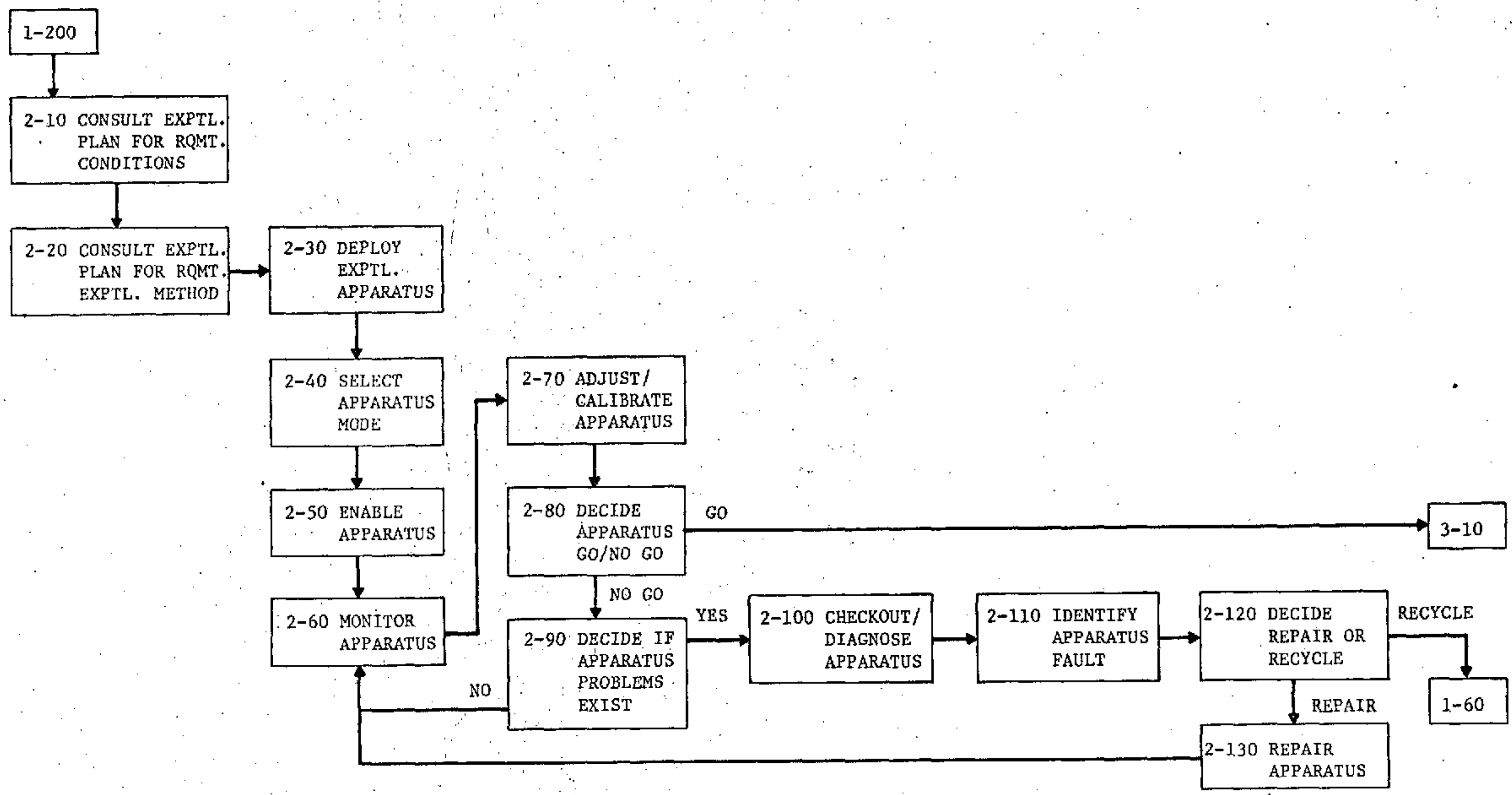

FIGURE 4-3. PHASE 2 - ENABLE APPARATUS

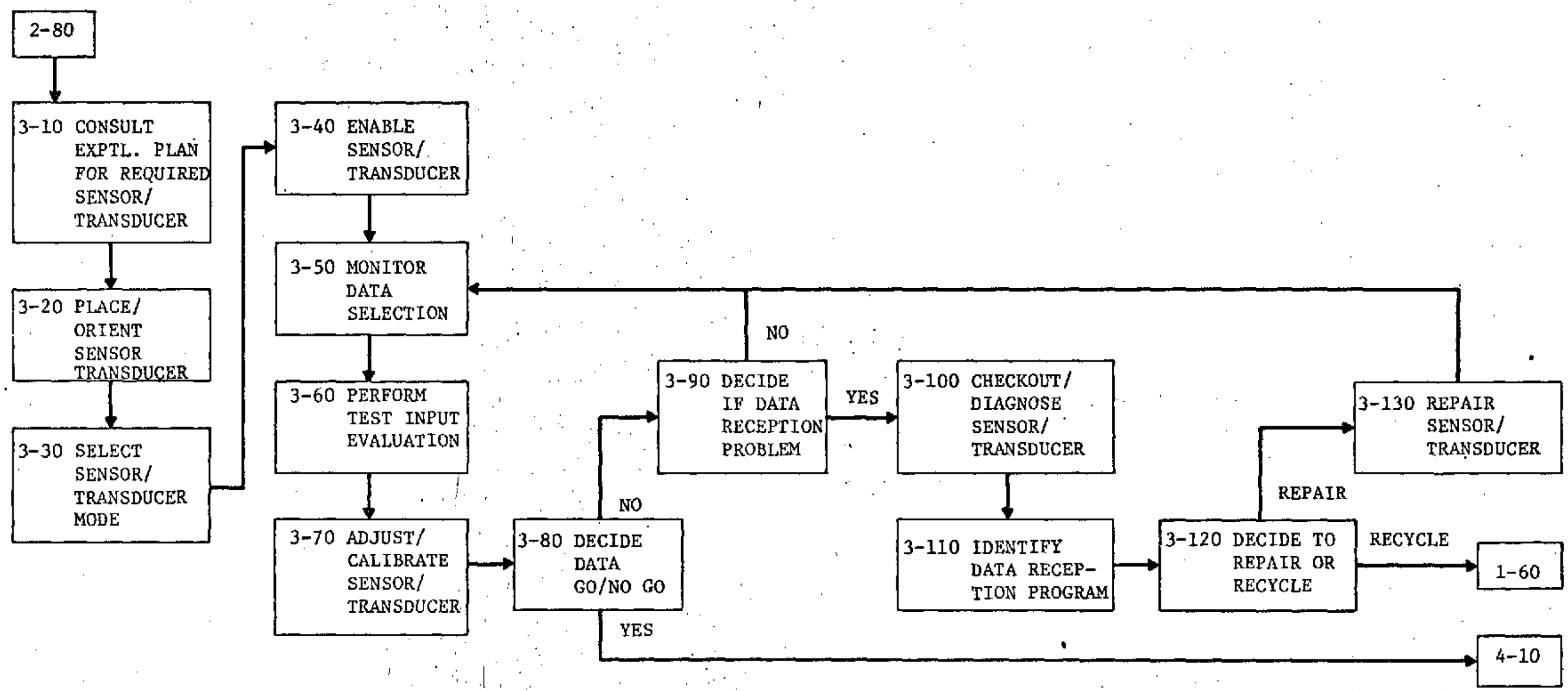

FIGURE 4-4. PHASE 3 - ENABLE SENSOR/TRANSDUCER

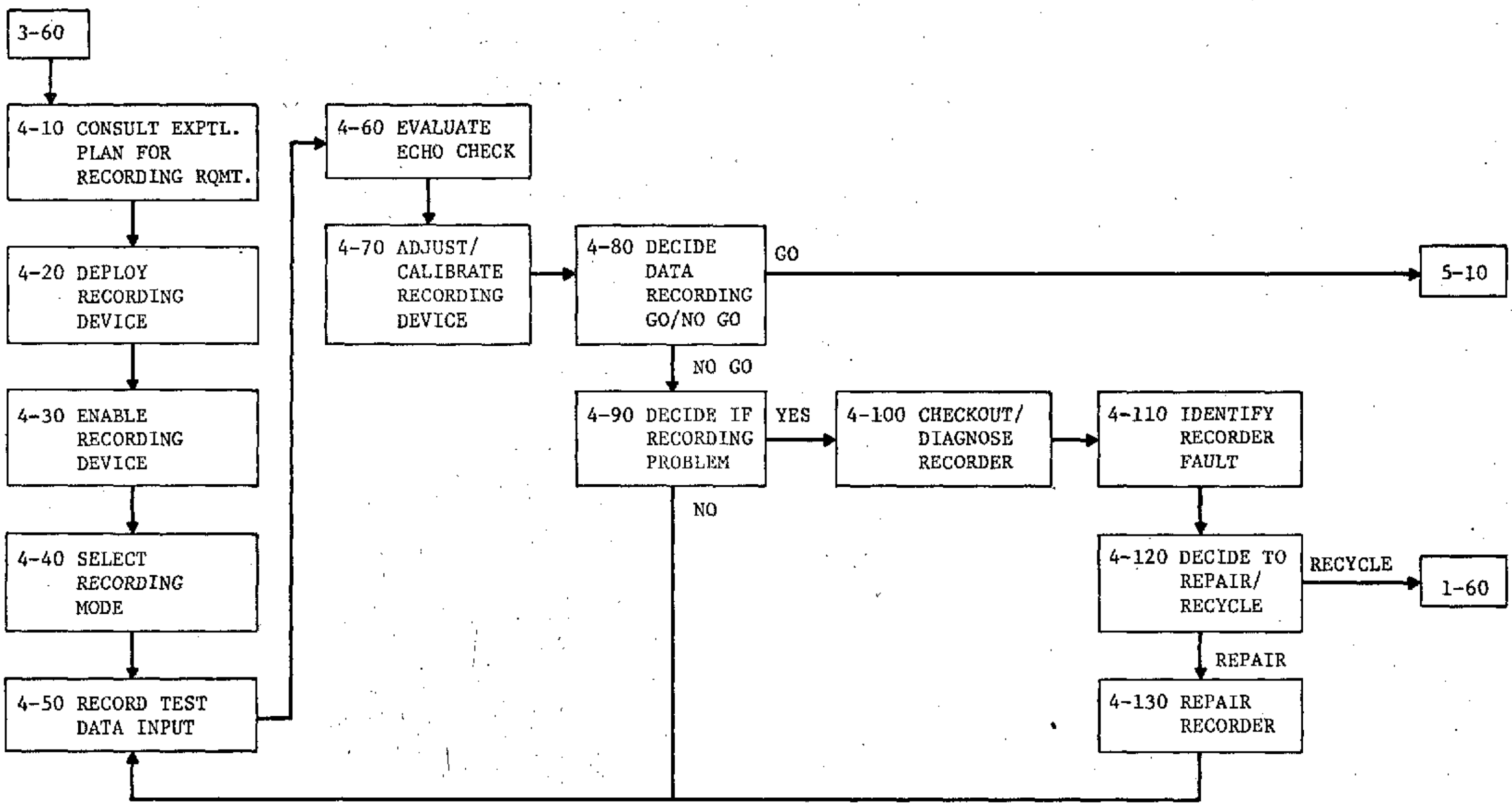

FIGURE 4-5. PHASE 4 - ENABLE DATA RECORDING

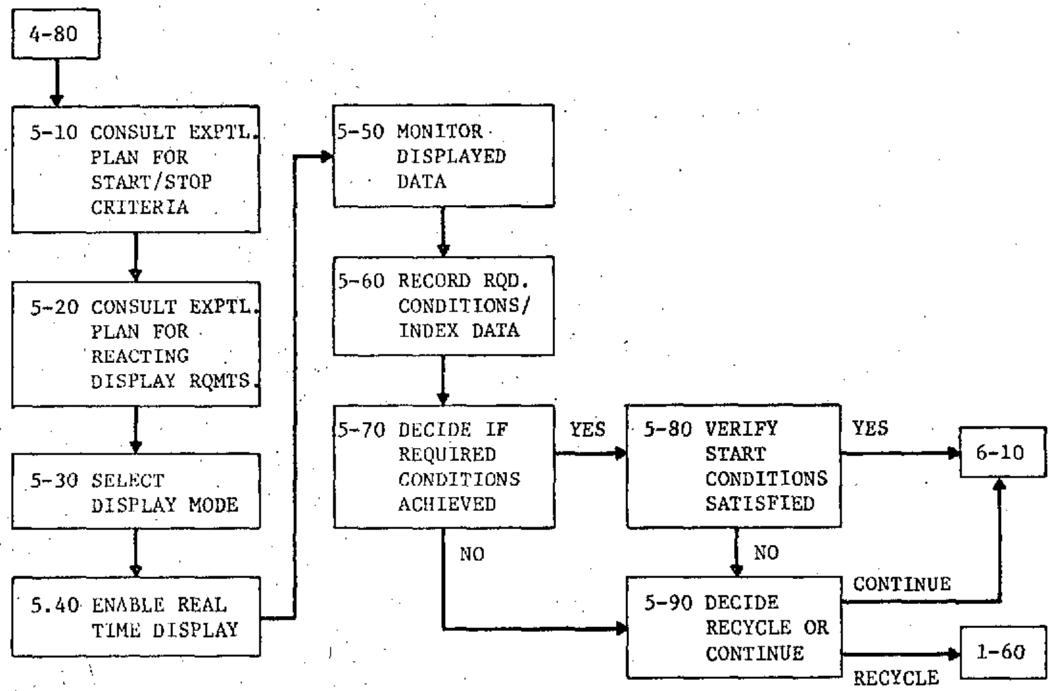

FIGURE 4-6. PHASE 5 - VERIFY READY FOR DATA COLLECTION

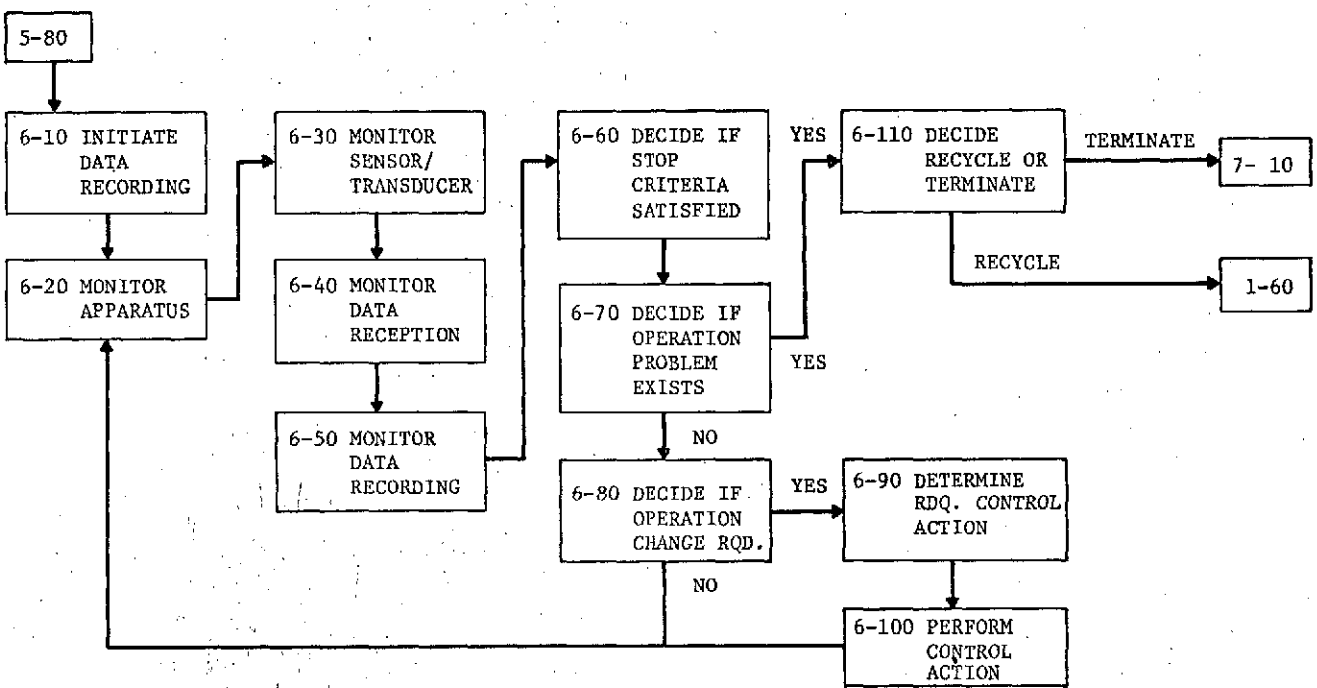

FIGURE 4-7. PHASE 6 - DATA RECORDING

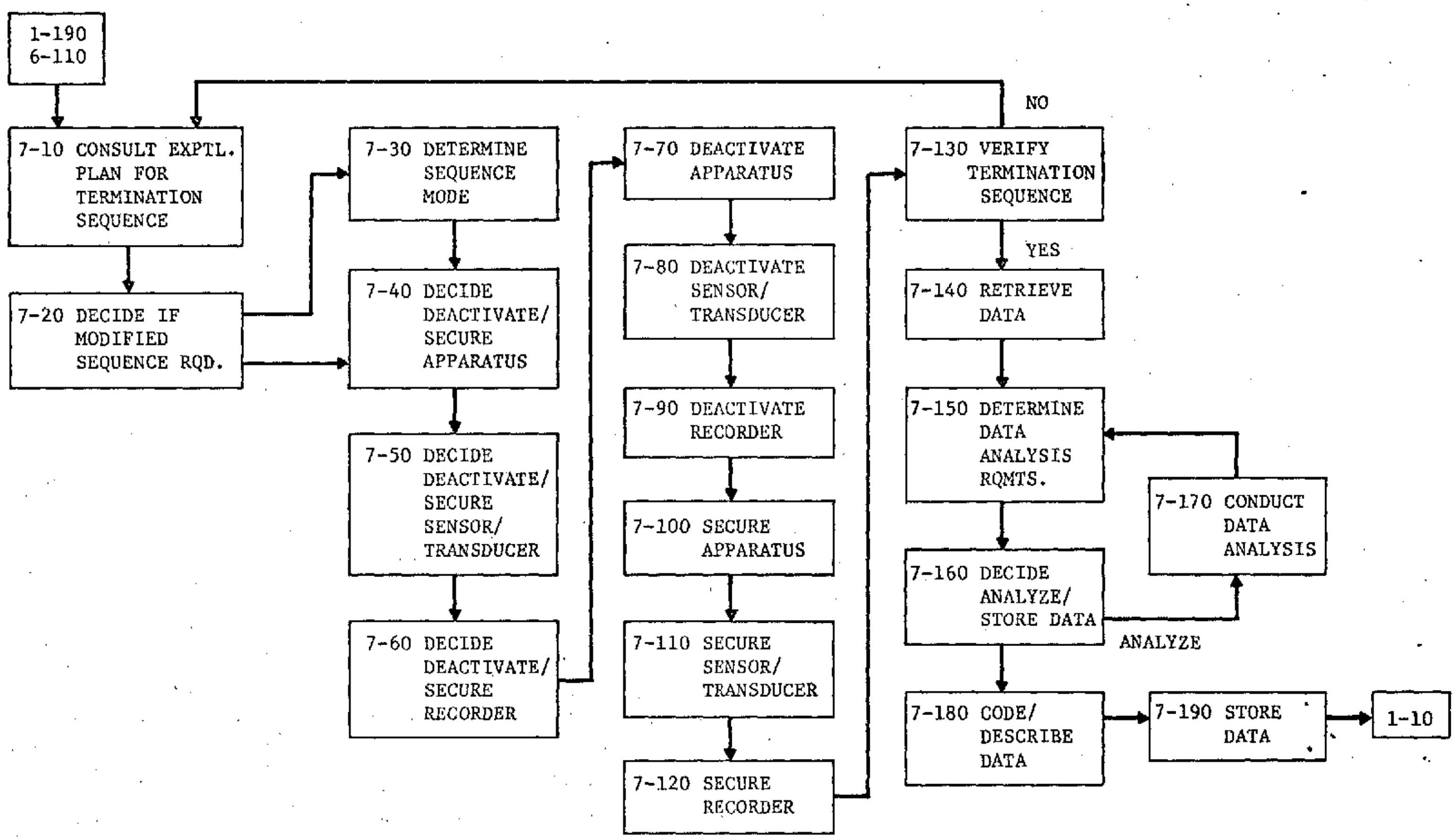

FIGURE 4-8. PHASE 7 – TERMINATION SEQUENCE

- Displays - The class of elements which recode transmission signals into energy sensible to the human observer.

- Controls - The class of elements which recode commands by the observer to electrical or other signals suitable for transmission within the system.

- Recording System - The class of elements which produces a permanent record of events and variable levels.

- Experimental Apparatus - The class of elements which modify the phenomenon of interest to match required conditions.

- Phenomena - The characteristics, processes, or effects of interest to the experimenter relative to:
    - celestial targets
    - the earth, its atmosphere, & magnetosphere
    - samples, materials, or objects in or near the shuttle

- Data Analysis Subsystem - The class of elements which carry out transformations of transducer outputs.

On-orbit operations may be divided into three phases - deployment/set-up, experiment operations, and final termination. Since the present effort deals with experimental operations, launch and de-orbit activities are beyond its scope and have not been dealt with.

The flow diagram for experiment operations details the performance of one experiment. An experiment is viewed as divided into seven phases as described below & as shown in Figs. 4-2 to 4-8. Phase 1 Experiment Selection - This phase involves specification of the next experiment to be performed. Experiment selection may range from simply consulting a prepared schedule where the experiment is strictly pre-planned to modifying the entire sequence of operations based on data already collected or the detection of targets of opportunity. Phase 1 also includes evaluation of modifications to the experiment based on revised planning or equipment degradation.

Phase 2 Enable Apparatus - The second phase involves operations necessary to permit functioning of the experimental apparatus. This may involve initial deployment upon arrival on orbit or powering up if the experiment has been performed previously and the apparatus is in a deployed mode. The enable apparatus mode may be the primary operation in a given experiment. Life Sciences and Space Processing experiments typify this case since the operation of apparatus is necessary to produce the phenomena to be observed. Astronomy and Earth Observation missions generally represent the opposite extreme where no operations on the environment are required and passive observation of naturally occurring events characterizes the experiment. The exception to this generalization is provided by the cometary and meteoroid simulations within the Astronomy area. These missions clearly involve the use of experimental apparatus, as presently defined, to produce the phenomena to be studied.

Phase 2 may also involve assessment of apparatus degradation which may result in a decision to recycle the experiment operation to Phase 1 to evaluate modifications or rescheduling due to problems encountered during Phase 2. Alternatively, apparatus may be repaired within Phase 2 based on the nature of the problem. Phase 2 results in a go or no-go state concerning only the functioning of the apparatus.

Phase 3 Enable Sensor/Transducer - Phase 3 involves operations similar to those of Phase 2 but directed to the sensor and transducer subsystems. As in the case of Phase 2, Phase 3 can be considered as representing either initial deployment or experiment conduct. Sensor pointing control is a key feature of Phase 3. In Astronomy, High Energy Astrophysics, and Solar Physics experiments, sensor pointing and source acquisition would occupy much of Phase 3. Phase 3 would also include any transducer mode or calibration procedures and monitoring of test inputs. Diagnosis and repair of sensors and transducers would also be included on a contingency bases.

Phase 4 Enable Data Recording - Phase 4 involves enable and check-out operations similar to those of Phases 2 and 3 but applied to the recording system. Preparation for real-time data analysis prior to recording data as inidcated in Figure 4-5 would be included in these operations. Phase 4 requires enabling and verifying the transfer of information to the recording system. The case of photographic recording at the sensor focal plane as in the case of many astronomical missions presents some problems in the current concept. This case might better be considered as one where preparation for recording is included in sensor/transducer set-up. The logic of Phase 4 is considered to be equally applicable to data recording on board or real-time transmission to the ground. Any contingency repair of the recorder system would also be included in Phase 4.

Phases 2, 3, and 4 thus constitute sequential separate go/no go decisions for the apparatus, sensor/transducer, and recording systems. Go decisions are required for the three systems in order for the experiment operation to continue.

Phase 5 Verify Ready for Data - Phase 5 involves an experiment system integration checkout and verification of start conditions for the experiment. In Phase 5, the observer enables any required real time displays of experimental data not enabled in previous phases. The scientific requirements for starting data recording are also verified during Phase 5. These requirements include:

- Sensor pointing, acquisition of the proper source, and reception of required dependent variables.
- Experimental apparatus functioning in terms of independent variables and their levels.
- Support system operation such as cooled IR telescope temperature.
- Verification of prior operations results.

Phase 6 Data Recording - Phase 6 entails real time control of experiment subsystems to maintain the conditions achieved in Phase 5. The observer may close the loop between data outputs and controlled parameters of the experiment including apparatus operation and sensor pointing. Alternatively to or in conjunction with control activities, the observer may monitor the experiment operation to detect off-nominal problems or satisfaction of the criteria for stopping the experiment. The outcomes of Phase 6 are processed either for recycling to modify the experiment or for termination of the experiment.

Phase 7 Termination Sequence - Phase 7 involves the activities required following a decision to end the experiment being performed. Phase 7 may apply either to interim termination within the repetitive cycle of an experiment or to final termination in preparation for de-orbiting. Phase 7 is thus envisioned as involving various combinations of deactivating or securing apparatus, sensors/transducers, and/or recording systems. Operations involving retrieving materials subjected to experimental manipulations as in the case of Life Sciences or Space Processing missions would be included in the apparatus subsystem termination. Film retrieval would be included in the sensor/transducer and/or recording system operations. The termination sequence might thus vary from switching off power to various experiment systems to complex retrieval and stowing activities including such operations as focal plane access and EVA.

A final aspect of termination would be data analysis and disposition of data. This might involve on-line data analysis, data analysis in parallel with operation of other experiments, coding of data for later analysis, or various recording processes such as stowing records or dumping recorded data to the ground.

The first level flow of experiment operations discussed above proceeds from initial set-up to final termination. The single experiment approach places the level of description at the payload level. An experiment is viewed here as a set of operations involving a particular set of system elements and resulting in the acquisition of certain sets of data. It is not necessary that an experiment as the term is used here be unitary in terms of scientific characteristics. Several phenomena, independent variables, or dependent variables may be processed in parallel within a single operational flow. An experiment as used currently defines some set of operations, hardware, and resources (such as power or man-hours). The present flow diagrams thus attempt an operational rather than scientific description of experiment operations.

4.2 - Level of Description of Flow Diagrams

The level of description of Spacelab operations refers to the amount of detail available from a flow diagram of the operations. What are described herd as Level 1 and 2 diagrams refer to experiment operations. These flows are thus a breakdown of a larger flow element termed on-orbit operations. The level 1 experiment flow discussed above breaks the single experiment into phases which reflect the level of description available from the SSPD Level II data sheets.(Ref. 4). The correspondence between the present flow

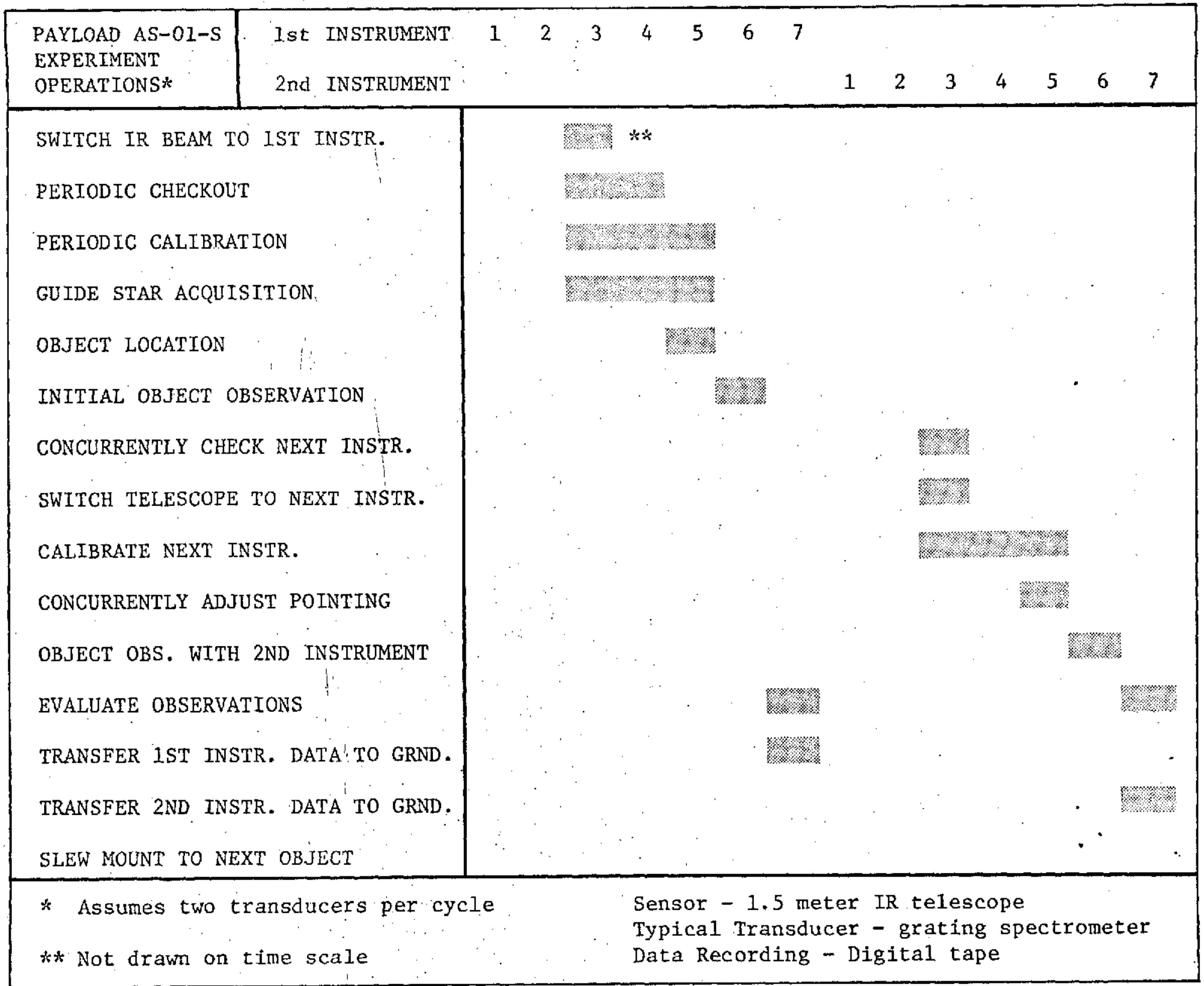

FIGURE 4-9. RELATIONSHIP OF FIRST LEVEL PHASES TO EXPERIMENT OPERATIONS FOR PAYLOAD AS-01-S

process and the specific experiment operations given for payload AS-01-S, 1.5 Cryogenically Cooled IR Telescope, by the July 1973 SSPD Level B Requirements Data (Ref. 4), is illustrated in Figure 4-9. The levels of description of the SSPD operations and the top level flow of Figure 4-9 may be seen to match fairly well. However, the given operations do not provide time for Phase 1 planning and modification activities. Phase 2 activities do not show up since the experiment is one involving passive observation.

The approach to obtain specific experiment operation flow data used in the current study was to detail the second level functions within the Phases of Figure 4-2 to 4-8. The descriptors of these functions for a particular experiment are discussed in a later section. These second level flows assume considerable latitude for decision making and procedure modification by the scientific crew during an experiment. In cases where this flexibility is not included in the mission, the appropriate functions may be dropped from the flow model. The second level flow diagrams thus represent an attempt to model the functional requirements of a Spacelab experiment at a completely general level without reference to specific missions or hardware. Some of the characteristics of the resulting flow network are listed below:

- Activities are represented by nodes in the network.
- Branches between nodes represent alternative paths and outcomes.
- Time is utilized in completing the activities.
- The duration of each function is assumed to be a random variable.
- The branching in the network may be probabilistic.

- Estimation of the function duration and branching probabilities of the network would permit mathematical simulation of the experiment.
- The difference between the generalized flow for Spacelab experiments and a specific experiment flow is that the latter involves unique values of the parameters of the generalized network.

Activities-on-node - The general form of the second level network involves activities as the network nodes. This feature is one employed in many graphical methods including PERT charts and digital program flow charts.

Alternative Branches - The arrows in the network represent the branching logic. Branching may be probalistic as in the case of equipment malfunction or may represent a logical decision process based on results obtained from functions previously completed or other factors. The branching logic of the generalized flow network is described in Appendix II.

Function Completion Time - The time consumed in completing a particular function is not likely to be a constant value where human observers are involved. Completion times for tasks performed by human operators are characterized by a probability distribution which describes the likelihood of completing the task after a specified duration.

Network Simulation - The network model is characterized by function duration distributions and branching rules. Assuming that these can be estimated, the operations modelled by the network can be simulated to determine the probability of completing the network within a specified amount of time. The model can be varied parametrically to study effects of:

- Crew size
- Crew composition and skill mix

- Crew member location-ground or on-orbit
- Automation of some functions in the network
- Design studies to optimize the man-machine interface
- Procedures

The present flow network model was developed to establish a technique for trade studies regarding the roles, responsibilities, and performance of man in Spacelab experiment operations. The generalized second level flows represent a point of departure for development of specific experiment netowork models and parameterization of these models.

5.0 SPECIFIC EXPERIMENT CREW FUNCTIONS

The approach selected for obtaining functional flow sequences for specific Spacelab experiments involves modifying the generalized flow model presented in Section 4.0 to reflect the operations and constraints of the experiment in question. Doing this requires estimation of a large number of free parameters of the general model. These parameters or characteristics fall into two classes. Network characteristics involve the placement of individual functions in the network and include:

- Sequential order - the ordering of phases or of functions within phases may differ from the ordering given in the general model due to the nature of the experiment.
- Parallel operations - certain functions may be performed in parallel or time-shared. In such cases, their durations would not be additive.
- Branching logic - the logical or random rules for determining the next function in the sequence may differ from the branching provided in the general model.

Function characteristics describe the nature of the individual function independently of its location in the network or its relation to other functions. Network characteristics and function characteristics may be described by functions despite the fact that they are conceptually different. The entire set of characteristics for one function in a specific experiment model are described below.

The specification of function characteristics which will determine an entire experiment flow model presupposes that the functions applicable to an experiment can be listed exhaustively. This sort of listing has been carried out for Spacelab experiments in the Life Sciences area (Ref. 15). Currently, however, the available listing is discipline-exhaustive. It includes all functions which might be carried out for <u>any</u> Spacelab experiment. The approach being described assumes that the functions to be performed in a <u>particular</u> experiment can be listed. Given this list, a complete network model would specify the network and individual function characteristics associated with each function:

5.1 - Function Parameters

The characteristics of a particular function include the following classes of information:

- Function Identification
    - Discipline
    - Payload/Experiment
    - Number & Name
- Criteria to Begin Function
    - Predecessor Functions Required
    - External Conditions Required
    - Information Required
- Criteria for Function Completion
    - Possible Outcome States
    - Decision Requirements
    - Action Requirements
    - Accuracy/Available Time Constraints
- System Elements Involved
    - Experimental Apparatus
    - Materials/Expendables
    - Sensors
    - Transducers
    - Displays
    - Controls
    - Recording Systems
    - Human Operators
        - Investigator
        - Experimenter
        - Technician
- Branching Logic Based on Outcomes
- Performance Estimates
    - Completion Time
        - Minimum
        - Mean
        - Maximum
    - Error Modes
    - Function Criticality

5.1.1 - Function Identification

Function identification data serve to facilitate data processing. The current system is illustrated in Figures 4-2 to 4-8. Each function in the general model is assigned a name and a number. The number identifies the phase and a three digit function indicator. While it is not necessary that the function indicator reflect the order of the function in the sequence, it is convenient if it does. For this reason, the function numbers in the general model are incremented by ten to permit interpolation of additional functions in the description of a particular experiment.

5.1.2 - Criteria to Begin Function

Predecessor Functions Required - Predecessor functions serve to describe the position of the function in the network. A predecessor function is one which must be completed in order for the function in question to begin. A function which has one or more predecessors cannot be started until these predecessors have been completed. The predecessor output is necessary for performance of the function in question. If a function has no predecessors, it may be started based on other start criteria.

External Conditions - External conditions include environmental and other factors which have to be in specified states for the function in question to be started. Where the crew has control of these factors, external conditions may be satisfied by completion of crew control and monitoring functions. Examples of external conditions which the crew does not directly control include:

- Availability of planned targets or sources -
  Target areas on earth - Earth Observations
  Stellar sources - Astronomy
- Out-gassing/contamination constraints

- Targets of opportunity - Astronomy
  - High Energy Astrophysics
- Magnetic field state - Plasma Physics

Much of the nominal mission planning carried out for a particular mission will involve the factor of planned target availability. The selection of orbital parameters and launch dates to maximize viewing opportunities is the primary goal of at least two efforts presently in progress. One is the MASS (Manned Activity Scheduling System) (Ref. 13) which was developed by Langley Research Center and applied by Langley to scheduling operation of the Advanced Technology Laboratory. MASS has been used to analyze viewing opportunities and viewing times for selected earth targets. A similar program applied to stellar sources is the AESOP (Automatic Event Program - Ref. 12).

Both efforts deal with source availability in terms of the amount of time that the source in question is within the slewing capability of the required sensor. These programs thus deal with scheduling observations to coincide with viewing opportunities. This optimized schedule is then incorporated into the mission timeline. The relationship of the current effort to these scheduling and timeline analyses is that the MASS and AESOP programs address the question of available time for the experiment operation in terms of the nature of the experiment functions, the size and composition of the crew, and the procedures employed. The available scheduling programs and the anlaytic methodology being developed in the present effort compliment each other in that together they address both timeline development and likelihood of timeline realization or the probability that the functions which comprise the observation will be completed during the available time for observation.

Information Requirements - The crew member in a Spacelab mission is viewed as receiving information as input, making decisions, and performing actions as outputs. The information requirements of a particular function are therefore starting criteria for the function. The crew member may need numerical displays, pictorial representations, discrete indicators, or printed material to gain the information he needs to perform the function in question. These information requirements are thus criteria for starting a function. They must be adequately input to the operator for him to accurately complete the function.

5.1.3 - Function Completion Criteria

Possible Outcome States - Outcome states refer to functions which may terminate in more than one mode or result. For example, during closed loop control of an experiment, the observer may have to decide if a controlled parameter is within a tolerance required by the experiment. The general flow model was constructed to reflect function outcomes in the branching logic. This may not be true in all cases, however.

Errors on the part of the operator are a form of alternative outcome states. Where a function could be completed incorrectly, this could be reflected in the branching logic if later diagnosis and action on the part of the operator can correct the error. If the error would not be detected, however, this could be considered as a correct and incorrect outcome state and, given suitable parameter estimation, could, be reflected in the measure of success probabilities.

Decision Requirements - Many functions included in the general model require that the operator decide between alternative courses of action. The set of actions, the information on which the decision is based, and the rules and decision aids (computational or otherwise) for reaching a decision constitute a procedural description of the function in question.

Action Requirements - Action requirements specify the nature and required accuracy of the operator output. The nature of the action is a primary driver of the controls and feedback displays which are utilized by the operator. Action requirements may also include time constraints on the completion of the individual function.

5.1.4 - System Elements

System elements have been described in Section 4.0. The nature of an experiment peculiar function depends largely on the type of equipment being used to perform the function.

Experimental Apparatus - Apparatus as used here refers to hardware used to produce, modify, or control the phenomenon of interest to the experimenter. Examples of apparatus are shown in Table

Materials/Expendables - Materials and expendables in the experiment context refer to items such as specimens and their life support expendables in the case of Life Sciences, objects to be subjected to experimental manipulations in the Space Processing area, and film in the case of Astronomy.

Sensors - Sensors include the experiment hardware which receive energy directly from the environment. Telescopes typify sensors.

Transducers - Transducers receive energy from the primary sensor and transform the energy to suitable form for transmission within the Spacelab system. Instruments such as photometers and spectrometers serve as examples of transducers.

Displays - Displays transform signals transmitted within the Spacelab to energy sensible to the human operator. Displays are closely connected to information requirements in that the primary data for role of man considerations are the nature of displayed variables derived from the sensors, apparatus, transducers, and other system elements. The information received and processed via displays is thus essential for the current effort. The physical nature of the sub-systems themselves are of lesser importance.

Controls are the system elements whereby the observer issues outputs which modify the operation of the experiment system. As in the case of displays, the primary data for the current effort involve the information aspects of system control - the parameters to be controlled by the observer.

Recording Systems - Recording systems refer to the system elements used to produce a permanent record of the events of interest in the context of the experiment. Data recording is of primary interest here in cases where the observer and recording system are interactive in the course of the experiment as would be required for data filtering or data compression.

Human Operators - The scientific observers involved in a particular experiment are described in the present effort in terms of discipline/specialty, scientific skill level, and technical skill level. The role/skill definition approach reported in Ref. 2 is employed for skill requirements description.

5.1.5 - Branching Logic Based on Outcomes

A second level description of a Spacelab experiment is unlikely to be linear or composed of a fixed sequence of functions. Since the ability of the human observer to modify the experiment based on prior data or system degradation, to respond to phenomena of opportunity, and to selectively record data is considered an important aspect of operational flexibility, the operational sequence representing an experiment will show decision points, branching based on experiment outcomes, environmental events, and system element functioning, iterations and other departures from a linear task sequence.

Branching logic is therefore a feature of the single function data to be input to the trade-off method. Branching logic specifies the next function(s) to be performed upon completion of the current function. Branching logic also specifies the mechanism for choosing the next function whether it is based on some logical decision process or takes place randomly in accordance with some probability function.

5.1.6 - Performance Estimates

Performance estimates comprise a set of function parameters having to do with the impacts of observer capabilities and limitations on the performace of the experiment system. Performance estimates include the following:

Function Completion Time - In order to deal with the statistical nature of obtained completion times, the function description includes estimates of the minimum, mean and maximum completion time statistics. The exact definition of these quantities is described in Appendix I. The completion time statistics may also be made conditional where they would be influenced by observer skill level, design features of the experimental hardware, external conditions, etc.

Error Modes - Error modes are categories of human error which would impact realization of experiment goals. Where such modes of potential errors exist due to the nature of aspects of the experiment, they are incorporated as either data degradation factors, or modifications to the branching relationships in the operational sequence. As in the case of completion time, error modes may be made conditional on observer and hardware characteristics.

Function Criticality - Function criticality, although not a human performance parameter *per se* is included here since it represents an index of the impact on experiment conduct of failure to perform a particular function or the occurrence of an error in function completion.

The specific function data outlined in the above discussion provides the input data for the representation of a particular Spacelab experiment by an operational sequence diagram model. The data also permit parameterization of the model insofar as the function descriptors can be assigned fixed values. Where these values cannot be assigned, the corresponding parameter is assumed to be free and to be subject to exercise of the trade-off methodology. Collection of function descriptor data for a particular Spacelab experiment thus constitutes the step from the generalized flow depicted in Figures 4-2 through 4-8 to a specific sequence model for a single experiment.

6.0 ROLE OF MAN TRADE-OFF METHODOLOGY

The methodology developed under the current effort represents a partial completion of the objectives stated in Section 2.0. The primary elements resulting from the current effort include:

- A generalized flow model for Spacelab experiments based on functional requirements
- A set of functional descriptor worksheets and accompanying method for communicating functional data
- Identification of an existing digital simulation program capable of exercising the functional flow model and providing data on experiment completion time and likelihood

The general flow model has been discussed in Sections 4 and 5. The functional descriptor approach is discussed in Section 5 and the details of data collection are presented in Appendix II. The computer program and associated trade-off methodology is discussed in the remainder of this section.

6.1 - Nominal Timeline Planning and Realization

Planning of nominal timelines is beyond the scope of the present effort. This is due to the fact that for many missions, the nominal planning is not primarily driven by role of man considerations. Nominal planning is more often constrained by orbital parameters and the coincidence of sensor envelopes with targets of interest. The methodology for constructing planned observational sequences is available in the form of several activity scheduled programs as discussed earlier (Refs. 12, 13). Given that the viewing opportunities or other physical constraints drive the construction of nominal timelines, the question of timeline realization arises. That is, "Will the scientific crew, operating under some allocation of the experiment functional requirements, complete the experiment within the time available under the planned timeline?". Under the problem definition used here, the determination of the role of man involves specifying role of man parameters which will result in realization of the requirements of the nominal timeline.

The present approach involves considering the entire experiment as a sequence of functions or tasks to be performed by the scientific crew. The determination of the probability of completion of the sequence within some time limit specified by the nominal timeline is considered in detail in Appendix I . This analysis shows that difficulties arise in summing individual function times to estimate total sequence times. Appendix I discusses problems associated with a strictly linear sequence of tasks. The problem is compounded if the operational sequence for a particular experiment involves branching - selection of following tasks based on random processes (as in the case of equipment degradation) or based on decision logic (as in the case of experiment modification resulting from analysis of prior data).

6.2 - Digital Simulation Program

During the course of the present study, a computer program was identified which was designed to simulate mission outcomes based on a modeling approach involving graphical representation of a task network. The program, termed System Analysis of Integrated Networks of Tasks (SAINT), was originally developed to study aircraft crew performance (Ref. 16).

In the current context of Spacelab experiment operations, SAINT accepts, as input, three major classes of data:

- The network relationships between a series of tasks or functions which comprise an experiment

- The descriptions of the individual tasks in terms of duration statistics, likelihood of operator error, and task criticality

- The descriptions of the available operators in terms of skills (which determine the tasks an operator can perform) and skill level in terms of speed and accuracy of performance

The specific crew function approach described in Section 4.0 is designed to provide the necessary input for SAINT data processing. Given suitable input data, SAINT simulates the experiment operations as described by the input data. Operators are assigned to perform tasks in the order described by the input data. When a task is performed, a single sample of task duration is drawn from the appropriate duration distribution via a monte carlo subroutine. The sample value drawn may be modified according to a model which reflects operator skill, stress, fatigue, level of practice, and other factors. The run terminates when the final task in the sequence is performed. Statistics may be collected at any point in the network. These data indicate total time distributions, completion likelihoods, delays between task completions, and operator utilization. To compile statistical samples of these parameters, multiple runs of the experiment are employed.

The basic SAINT model consists of nodes, representing tasks, and branches, indicating precedence and sequencing relationships among the tasks, which form a network. Moving through this network are operators which perform the tasks according to data peculiar to each task node and individual operator characteristics and limitations. Each task node has certain parameters associated with it.

- Preceding task completions necessary for first initiation

- Preceding task completions necessary for second and subsequent initiations

- Specific distribution curve types and parameters for task duration from which samples are obtained.
    - constant
    - normal
    - uniform
    - erlang (including expontial)
    - lognormal
    - poission
    - beta
    - gamma
    - beta fitted to 3 values (as in PERT)
    - constant equal to the parameter set number divided by a scale factor
    - triangular

- Task type
    - single operator task - one operator may perform task
    - joint operator task - two or more must perform
    - either of two or more operators
    - equipment task
    - cyclic task
    - gap filler task

- Degree to which the task is essential relative to other tasks to be performed during the mission.

Statistics may be collected on any task during a simulation run. Both graphical and numerical data may be obtained for each individual task node and for the overall system network performance.

Branching between each task is of five separate types:

- Deterministic - Subsequent tasks are performed upon completion of the task node unconditionally.
- Probabilistic - Either of two or more tasks may be performed, determined by the relative probabilities assigned to each outgoing branch from the deterministic task node. The sum of all branches must equal 1.0.
- Conditional branching, take first - Upon completion of the present task, flow will be to the first succeeding node which has

all other requirements for task initiation complete.

- Conditional Branching, Take all - Upon completion of the present task flow will be to all the succeeding tasks which have requirements for initiation complete.
- Modified Probabilistic Branching - Same as probabilistic branching except that the probability of the branch selected is increased by a pre-determined amount each time it is selected.

Each operator is assigned specific characteristics which affect the performance of the task nodes. These include speed and accuracy factors, stress thresholds and goal gradiants; any or all of which may be ommitted.

Once the SAINT user has determined data relative to task nodes, branching conditions and operator characteristics, preparation of an overall system network is possible. SAINT allows modification of this network during operation.

- Tasks may be deleted, substituted, or added under user specified conditions.
- Task parameters may be changed relative to distribution type, probability or essentiality.
- Operator characteristics may be modified to allow for efficiency increase through practice, stresses due to environmental factors, time limitations or equipment failures.

All information concerning task nodes, branching, operator characteristics, etc., are transferred to computer cards for input to the main SAINT program. Using the symbology suggested by the SAINT simulation method facilitates preparation of the data deck input as all data deck information is immediately available from the completed network.

At present, the SAINT source deck has been obtained and checked out and is operational at the NASA MSFC computation laboratory. During the next phase of the effort, data on specific crew functions for selected experiments will be input to SAINT to permit quantitative determination of role of man parameters required to realize experiment goals.

6.3 - Exercise of Role of Man Methodology

The methodology developed during the present study is described in Figure 2-1 which depicts the flow of the conduct of role of man trade-offs for a specific Spacelab experiment or mission. The approach depicted is performed via seven primary elements:

- Collection of functional requirements data via the process described in Section 5.0.
- Construction of an appropriate operational sequence diagram for an experiment or mission.
- Determination of role/skill requirements as described in Ref. 2.
- Development of allocation candidates based on the above steps.
- Preparation of SAINT input based on the above steps.
- Conduct of SAINT data runs.
- Trade studies using SAINT output to identify acceptable allocations.

7.0 - CONCLUSIONS AND RECOMMENDATIONS

The present study was directed toward development of a methodology for establishing the role of man in specific Spacelab experiments. This objective necessitated some efforts to narrow down the concept of "role of man" and to provide an operational definition of the role of man and of the process for its determination.

The approach taken to this problem, as indicated in the present report was to define the role of man in terms of functional allocation. The role of man is considered to be defined by the functions or tasks he performs in the course of a Spacelab experiment. This approach has the advantage of providing an analytical approach to crew role determination. The view is taken here that crew time is a resource to be allocated to Spacelab experiments and operations much as would any other resource. The methodology developed here provides an approach to obtaining quantitative indications of effects of crew size and skills on experiment objective realization.

In the method developed here, the functional flow model of a Spacelab experiment is the starting point. The approach then requires construction of several functional allocations. These allocations vary in terms of crew size and the functions assigned to each crew member. Processing these allocations via the SAINT program then yields predicted measures of the degree to which the experiment goals are realized in terms of:

- Experiment completion time
- Experiment completion probability
- Amount of data recorded
- Degradation due to human errors

These statistics can be expressed as <u>effectiveness measures</u> for the allocation candidate in question. The results of several allocations may then be cross plotted to conduct trade studies. One obvious penalty of increased crew size is weight. Since additional crew members result in a certain weight penalty and a certain effectiveness level, this trade could be performed directly from data output by the SAINT program. For a given crew size there will also be an impact of variation in crew performance based on degree of training and cross training of crew members. One would expect this impact to decrease as additional crew members are added. The maximum effectiveness level attainable by training at a fixed level of crew size would be limited by the workload requirements of the experiment. If parallel or simultaneous operations are involved, cross training would not address this problem.

Reducing the crew size for a particular mission would obviously entail assignment of a wider range of tasks to each operator. The number and nature of these functions would then be directly translatable into training requirements. Since training content and extent would influence mission preparation time, a second crew skills trade could be conducted in this area.

While the above discussion does not exhaustively list the trade studies which could be performed based on SAINT output, it does indicate that the methodology developed provides a direct approach to the objective of determining optimum crew role determinations for Spacelab experiments.

The method further indicates data requirements for quantitative study of the role of man. As is pointed out in Sections 3 and 4, the application of the present methodology requires a greater level of detail on functional requirements for Spacelab experiments. Since the conclusions reached by application of the methodology rest on the validity of the input functional requirements data, the next step in the effort to define the role of man should be collection of detailed functional requirements data for selected payloads. The determination of the nature of the required data was carried out during the present study.

While the form of the required functional requirements data is well understood, the question remains as to the source of such data. These data should be solicited from at least three sources:

- Payload planners - The nature of the experiments to be performed in terms of the operational sequence can be obtained only from the working groups, principal investigators, and cognizant NASA and contractor personnel. These sources should be relied on chiefly for precedence and branching data, required condition, information, decision, and action requirements, and skill requirements.

- NASA and contractor simulation data - At present, numerous experiment simulation operations are being conducted and planned. These include functional mockup efforts performed by payload planners, CVT simulations conducted at MSFC, and the ASSESS program at ARC. Data from these efforts should provide information on workload, completion time and error variables - particularly where functions have not previously been performed on orbit.

- Manned spaceflight experience - Where functions defined for Spacelab experiments are similar to those performed in previous manned vehicle programs, data from debriefings and operational summaries should be incorporated into the role of man effort.

Specific conclusions reached during the conduct of the present study include the following:

Conclusions

- The operational definition for determination of the role of man in Spacelab experiments is a trade-off approach based on the effectiveness of alternative allocations of functions to crew members.

- The data necessary to perform trade studies in the area of role of man are the detailed functional requirements for specific experiments.

- The detailed functional requirements data are not provided in the presently available payload data summaries.

Results:

- The detailed functional data for exercise of the methodology were defined in the current study and appropriate worksheets have been developed.

- The next step in the effort to define the role of man should be the collection of detailed functional requirements data from payload planners, Spacelab simulation efforts, and manned spaceflight experience. To accomplish this, the crew skills method of Ref. 2 were incorporated into the SSPD effort during the course of the study.

- Where possible, the conduct of Spacelab simulation efforts should be structured to provide the data identified as necessary for the role of man determination.

- Based on suitable input data, the methodology developed during the current study can provide the performance data for trade studies in the role of man approach defined above.

REFERENCES

1. Mulholland, D.R.; Reller, J.O. Jr.; Heel, C.B., and Haughney, L.C. Study of Airborne Science Experiment Management Concepts for Application to Space Shuttle - Volume II. NASA TMX-62, 287. Airborne Science Office. NASA Ames Research Center, July, 1973.

2. Malone, T.B. Role of Man in Shuttle Experiment Payloads. Essex Corporation, July, 1973.

3. Poulton, E.C. Tracking Behavior in Bilodeau, E.A. (ed.) Acquisition of Skill. Academic Press, 1966.

4. Space Shuttle Payload Definitions - Level B. NASA Marshall Space Flight Center, July, 1973.

5. Final Report of the Space Shuttle Payload Planning Working Groups, NASA Goddard Space Flight Center, May, 1973.

6. Payload Operation/Crew Function Workshop held at NASA Johnson Space Center, April 16-18, 1974.

7. Summarized NASA/ESRO Payload Descriptions. NASA Marshall Space Flight Center. October, 1973.

8. Space Shuttle System Payload Accommodations - Level II Program Definition and Requirements. NASA Johnson Space Center, December, 1973.

9. Spacelab User Implementation Assessment Study Rockwell International - Space Division

10. Crew Functions and Crew Stations for Support of Payload Operations. NASA Johnson Space Center. January, 1974.

11. Spacelab User Interaction Study, No. 74W-00044. IBM Federal Systems Division. February, 1974.

12. Fitzgerald, A.J. Astronomy Experiment/Experimenter Timelines Analysis. 9240-73-219, Northrop Services, Inc. August, 1973.

13. Study of Shuttle - Compatible Advanced Technology Laboratory (ATL) TMX - 2813, NASA Langley Research Center. September, 1973.

14. Sortie Lab User Requirements. NASA Marshall Space Flight Center, April, 1973.

15. Life Sciences Payload Definition and Integration, General Dynamics, July 1974, August 1973, March 1972.

16. Pritsker, A.A.B., Wortman, D.B., Seum, D.C., Chubb, G.P., and Seifert, D.J. SAINT: Systems Analysis of Integrated Networks of Tasks. Aerospace Medical Research Laboratory, Air Force Systems Command, Wright Patterson A.F.B. August, 1973.