N72-28091

DEVELOPMENT OF FLIGHT EXPERIMENT TASK REQUIREMENTS

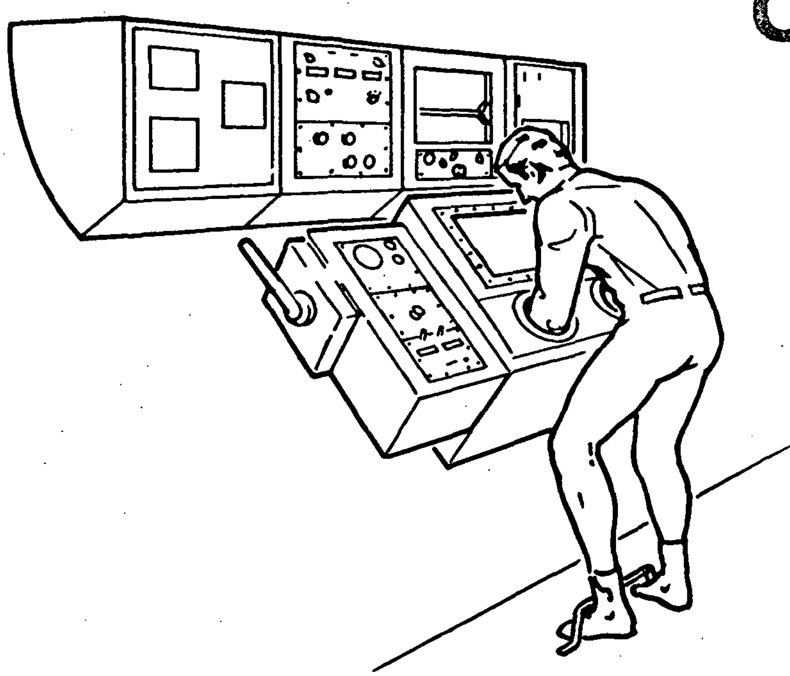
FINAL REPORT

CONTRACT NASW-2192

VOLUME I—SUMMARY

JUNE 1, 1972

PRL 189



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DEVELOPMENT OF FLIGHT EXPERIMENT TASK REQUIREMENTS

FINAL REPORT

CONTRACT NASW-2192

VOLUME I—SUMMARY

PREPARED FOR:

BIOENGINEERING DIVISION, OFFICE OF LIFE SCIENCES
HEADQUARTERS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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PRL 189

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June 1, 1972

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ACKNOWLEDGEMENTS

The NASA Technical Director for this study was Dr. Stanley Deutsch, Director, Bioengineering Division, Office of Life Sciences, NASA Headquarters, Washington, D.C. Valuable assistance in obtaining information and data and providing direction to the progress of the study was provided by Mr. Stanley Johns and Mr. Arthur Galzerano, NASA George C. Marshall Space Flight Center, Huntsville, Alabama.

The Principal Investigator for the contract was Kenneth M. Mallory, President, URS/Matrix Company, URS Systems Corporation. Project Director for URS/Matrix was G. Richard Hatterick. Principal contributors from URS/Matrix Co., Man Systems Division, to the conduct of the analyses reported herein were Dennis C. DeWitt, Leland C. Jones, and C. Dennis Pegden.

FOREWORD

This study contract (NASW-2192) was awarded by NASA Headquarters to develop the means to identify skills required of scientist passengers on advanced missions related to the Space Shuttle and RAM programs. The scope of the study was defined to include only the activities of on-orbit personnel which are directly related to, or required by, on-orbit experimentation and scientific investigations conducted on or supported by the Shuttle Orbiter.

This report provides a description of the methodology developed, an overview of the activities performed during the conduct of the study, and a presentation of the results obtained through application of the methodology.

The report is packaged in three parts, as follows:

Volume I : Program Summary
Volume II: Technical Report
    Part I : Program Report and Appendices A-G
    Part II: Appendix H - Task-Skill Data Sheets.

SUMMARY

Preliminary NASA studies aimed at definition of experiments and payloads for orbiting with the Space Shuttle system have included various types of crew skill requirements identification. The skill identification methods used, however, were inadequate, especially when applied to relatively undefined systems and configurations.

This study addressed the problem of determining, at an early stage in system/mission definition, the skills required of on-orbit crew personnel whose activities will be related to the conduct or support of earth-orbital research. The experiment data base was selected from proposed experiments in NASA's Earth Orbital Research and Application Investigation program as related to Space Shuttle missions.

Activities during the study, documented in this report, include identification of baseline Shuttle system/subsystem research functions and ten basic functions dealing with man's research and/or servicing activities on orbit. A Crew Function Taxonomy was developed relative to these activities. Likely candidate experiments for Shuttle Sortie and Shuttle supported free flyer missions were selected through extensive review of experiment and mission descriptions.

Crew tasks were identified for forty-eight representative earth orbital experiments, and a comprehensive task analysis was conducted on these tasks. Operating environments constraining each crew function in these tasks were defined.

Crew skill requirements for performance of the forty-eight representative on-orbit experiments were identified through a new technique, developed in this study, called Task-Skill Requirements Identification. The concept and procedure of this technique, including development of the Task Dependency Reference system, is discussed, along with conversion of Task-Skills to Occupational Skill Classifications. In addition, off duty/nonoperational task requirements for Shuttle experiment crew personnel are identified.

A comprehensive data base of crew functions, operating environments, task dependencies, and task-skills applicable to a representative cross section of earth orbital research experiments is presented. All data has been coded alphanumerically to permit efficient, low cost exercise and application of the data through automatic data processing.

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1.0 INTRODUCTION

1.1 SCOPE AND OBJECTIVES

Contract NASw-2192, under which the study reported here was conducted, had two primary objectives: (1) to develop a method by which the skills required of crew personnel for support of earth orbital research programs could be identified before system/mission configuration became fixed and (2) to apply the new methodology to a representative cross section of planned earth orbital research flight experiments in order to develop a data base of task and skill information relative to early Shuttle missions. The purpose of developing this information is to provide to mission planners, during system design and development, an additional basis for making decisions regarding payload content, configuration, and crew size, as well as policy, procedures, and objectives. Input data to be used in achieving these objectives were to be the most current descriptions of experiments and missions then available, encompassed primarily by the NASA Preliminary Edition of Reference Earth Orbital Research and Applications Investigation (Blue Book), NHB 7150.1, dated January 15, 1971 (ref. 1).

1.2 BACKGROUND

NASA's manned spaceflight programs during the 1960s were primarily aimed at qualifying man and machine systems for spaceflight and lunar exploration. In the 1970s, emphasis will change to utilization of manned spaceflight to perform research and technology experimentation in earth orbit, beyond the restrictions and constraints of the earth's atmosphere. Several such experiments have been conducted in the Apollo program, subsidiary to the primary mission of lunar exploration. The Skylab project will go further with experiments such as the Apollo Telescope Mount (ATM) studies of the sun. The primary purpose of Skylab, however, is to study the ability of man to perform effectively in space for long durations. Each of these programs, from Project Mercury through Skylab, will have added valuable knowledge about man in space, his spacecraft, the tools he needs in space, and the space environment. All of the crewmen on these missions will have been highly trained and dedicated astronauts, many having been military aircraft test pilots and some having commendable scientific credentials as well.

With the Space Shuttle (now in early development and expected to be available in the late 1970s), the United States will have the capability of placing experiment payloads in earth orbit for observation of the earth's surface, conduct of experiments and investigations regarding the space environment, or research into scientific and technological areas which capitalize on the unique characteristics of the orbital spaceflight environment. These experiment payloads will vary in content and purpose from small, self-contained orbital laboratories to orbiting automated research satellites to eventual experiment modules for a permanent orbiting Space Station. Preliminary definition studies are being conducted to identify the characteristics of the candidate experiments and the ways they may be grouped and/or combined into Shuttle mission payloads.

1.3 FLIGHT EXPERIMENT TASK REQUIREMENTS STUDY (NASw-2192)

Just as the nature of the missions being planned has changed, the duties of the experiment personnel will be very different from those of the pre-Skylab crewmen. These duties will involve setup and maintenance of sophisticated experiment equipment, decision making and control functions regarding the conduct of experiments, and, in many instances, the interpretation of collected data. Pre-Phase A studies of experiment requirements have recognized these changes by identifying and categorizing Functional Program Elements (FPEs)* and experiments by the "skill" areas which are reflective of the primary purpose of the experiment and the professional discipline or occupation involved. Figure 1-1 illustrates the "crew skill" categories listed in the Blue Book Summary volume (ref. 1) and their distribution across the FPEs described in that publication. Individual experiment descriptions within the Blue Book in some cases list additional and/or alternative skill categories to those shown. Other study reports and program documentation have included their own listings of needed crew skills, but most are similar to (and based on) the listing found in the Blue Book. The methods utilized to identify these skill areas were inadequate, however, when applied to relatively undefined systems and configurations. A need was recognized for a valid, flexible skill identification technique which could be applied during the early stages of system definition.

In support of the new role for man-in-space, a study was initiated to develop the means to identify the task performance requirements of the experiment module scientific and technical crews for the conduct of the planned types of orbital experimentation. This study, based on a sampling of representative experiments, is now complete and has confirmed the wide variety of skills which will be needed by the crew to work successfully with the projected experiment payloads. In the conduct of this study, Matrix Man Systems Division has successfully developed and demonstrated a technique for skill identification which is not dependent on traditional occupational titles with their inherent and frequently misleading connotations of expertise in technical and scientific areas. Rather, the technique permits identification of specific task performance requirements based on the purposes and objectives of either general or specific tasks and subtasks and the interfaces with certain items of equipment, facilities, and environmental factors. While avoiding the occupational implications during the analytical phase of determining task performance capabilities, the method retains compatibility with occupational and professional designations.

*The term "Functional Program Element (FPE)" describes a gross grouping of experiments that are each mutually supportive of a particular area of research or investigation and that impose similar or related demands on the orbiting research facility.

FIGURE 1-1: "Blue Book" Crew Skill Identification By Functional Program Element

DISCIPLINE	FUNCTIONAL PROGRAM ELEMENT TITLE	NO.	1 BIOLOGICAL TECH.	2 MICROBIOL. TECH.	3 BIOCHEMIST	4 PHYSIOLOGIST	5 ASTRONOMER/A'PHYS.	6 PHYSICIST	7 NUCLEAR PHYSICIST	8 PHOTOTECH/CARTOG.	9 THERMODYNAMICIST	10 ELECTRONIC ENGINEER	11 MECHANICAL ENGINEER	12 ELECTROMECH. TECH.	13 MEDICAL DOCTOR	14 OPTICAL TECHNICIAN	15 OPTICAL SCIENTIST	16 METEOROLOGIST	17 MICROWAVE SPECIALIST	18 OCEANOGRAPHER	19 PHYSICAL GEOLOGIST	20 PHOTO GEOLOGIST	21 BEHAVIORAL SCIENTIST	22 CHEMICAL TECHNICIAN	23 METALLURGIST	24 MATERIAL SCIENTIST	25 PHYSICAL CHEMIST	26 AGRONOMIST	27 GEOGRAPHER
ASTRONOMY	X-Ray	A-1					Δ																						
	Stellar	A-2					Δ	Δ																					
	Solar	A-3					Δ																						
	Intermediate UV Telescope	A-4					Δ	Δ																					
	High Energy Stellar	A-5					Δ	Δ								Δ													
	Infrared	A-6					Δ																						
PHYSICS	Space Physics Research Lab	P-1					Δ	Δ						Δ															
	Plasma	P-2						Δ						Δ															
	Cosmic Ray	P-3												Δ															
	Physics and Chemistry	P-4						Δ			Δ			Δ													Δ		
E.O.	Earth Observations Facility*	ES-1																Δ		Δ	Δ	Δ		Δ				Δ	Δ
C/N	Com/Nav Research Lab	CN-1										Δ		Δ		Δ			Δ										
MS	Materials Science & Manufact.	MS-1	Δ		Δ			Δ				Δ		Δ		Δ	Δ								Δ	Δ	Δ		
TECHNOLOGY	Contamination Measurements	T-1						Δ						Δ															
	Fluid Management	T-2									Δ			Δ															
	EVA	T-3												Δ															
	Advanced S/C Systems Test	T-4								Δ	Δ	Δ	Δ	Δ															
	Teleoperations	T-5										Δ	Δ	Δ															
LIFE SCIENCES	Medical Research	LS-1	Δ	Δ	Δ	Δ								Δ	Δ									Δ					
	Vertebrate Research	LS-2	Δ	Δ	Δ	Δ								Δ										Δ					
	Plant Research	LS-3	Δ		Δ									Δ										Δ					
	Microbiology Research	LS-4	Δ	Δ	Δ									Δ															
	Invertebrate Research	LS-5	Δ		Δ									Δ															
	Life Support & Protective Sys.	LS-6		Δ									Δ	Δ										Δ					
	Man System Integration	LS-7											Δ	Δ	Δ								Δ						

*Listing errors corrected.

2.0 RESULTS

2.1 METHODOLOGY DEVELOPMENT

One objective of this study was to determine the kinds of skills that would be required of on-orbit personnel in support of research and application experiments. The source documentation reviewed as part of this study, however, included listings of "skills" required for the experiments. An early conclusion reached in reviewing the experiment descriptions was that the documented "skill" assignments were, in fact, merely references to occupational and professional titles that appeared related to the type of experimentation or other activities to be performed (see Figure 1-1). Little evidence could be found that these "skill" assignments were based on an analysis of the actual tasks to be performed by orbiting crewmen. It was decided that, in order to determine the skills that would be required, the activities and tasks generating the requirements for particular skills needed analysis and that skills should be defined in such a way that they were independent of the connotations and associations of standard occupational and professional titles. It was further concluded that skills should be defined at a level that would be independent of factors such as crew size, specific equipment configurations, mission duration, experiment grouping within the payload, or facility characteristics. This led to the concept of "Task-Skills" which, basically, is to describe the skill requirement in terms which identify a particular function which a man must perform ("crew function") and the item or factor with respect to which the function must be performed ("task dependency").

2.1.1 Crew Functions

Essential to the identification of task-skills is the knowledge of the kinds of functions which a crewman is, or may be, expected to perform. Definition of these functions can take many forms but should, to the greatest extent possible, be mutually exclusive, provide insight to the intellectual, sensory, and motor activities of the crewman, and be independent of the nature of the equipment or experiment with respect to which the function is to be performed. During this study, and for purposes of utilization in the task-skill identification, the taxonomy of crew functions shown in Table 2-1 was developed. Definitions of these crews functions, included as Appendix B in Volume II, satisfy the criteria stated above. The crew function(s) together with the task dependencies (next paragraph) are utilized in specifying appropriate task-skills.

2.1.2 Task Dependencies

Within the context of task-skill identification, a "task dependency" is a factor upon which successful performance of a crew function depends. The nature of such factors covers a very broad range, and all have implications

TABLE 2-1: CREW FUNCTION TAXONOMY

No.	Title	No.	Title
01	Status Monitoring	18	Unstow
02	Observation	19	Clean and Decontaminate
03	Inspection	20	Assemble
04	Pattern Recognition	21	Disassemble
05	Communication	22	Translocation
06	Data Processing	23	Deployment
07	Fault Isolation	24	Retrieval
08	Calibration	25	Locomotion
09	Alignment	26	Removal
10	Control	27	Replacement
11	Evaluation	28	Repair
12	Analysis	29	Unknown
13	Decision Making	30	Subject for Experiment
14	Test and Checkout	31	Occupy
15	Actuation	32	Wear
16	Deactuation	33	Receive
17	Stow	34	Donate
Definitions of Crew Functions are included in Appendix B, Volume II			

for the knowledge, training, and/or experience which must be possessed by the crewman. It was determined, during the early stages of this study, that any efforts to identify crew skill requirements must of necessity identify the factors upon which performance depends. Further, these factors, or task dependencies, must be identified at the most specific level supportable by the input data, but they must not preclude progress of the analysis if specific identification is not possible. To achieve this goal, a determination was made of the major types of factors upon which successful performance depended. These major factors were categorized as:

1. System and Facilities
2. Experiment Equipment and Materials
3. Object or Area Under Investigation
4. Support Equipment
5. Environment

The five major categories of task dependencies were divided into subcategories based on major functional differences. Then, as each new item of equipment or object of investigation was identified, it was placed in one of the subcategories. Each item was given an alphanumeric code designation to permit ready recognition of the category and subcategory to which it belonged and to promote rapid data retrieval. In addition to these three levels, a fourth level was assigned, where appropriate, to identify specific equipment items or characteristics. Figure 2-1 illustrates the derivation of each level of the Task Dependency Reference List (TDRL) and the associated code. The complete listing is included as Appendix D to Volume II.

The utilization of the TDRL enables the analyst to specify the equipment, environment, conditions, objectives, etc. on which task performance depends to whatever level of specificity is supportable by program definition status and/or is needed by the purpose of the analysis. There is no need to determine precise equipment characteristics or to obtain serial numbers in order to document the item's relationship to the task. In fact, an equipment item which does not yet exist can be included (as a functional requirement) and can have the same consideration as those which are well defined. The TDRL further recognizes and incorporates the less tangible or less visible factors which affect task performance (e.g., an area of knowledge), and ensures that consideration is not limited to a specific item of hardware. It is expandable, condensable, and flexible and is designed to be a tool to aid in the conduct of analyses rather than a documentation of what has transpired.

2.1.3 Operating Environments

The "operating environment" was defined in this study as the environmental conditions under which the crewman must perform his assigned functions. The purpose of this identification is twofold. First, while the operating environment does not form a part of the skill requirement identification, by identifying the operating environment, constraints imposed by the environment on task performance can be identified. Secondly, identification of the operating environment provides an input to the Task Dependency Reference List, since "Environment" is one of the five major categories of dependencies. A listing of the operating environments identified during this study is provided in Table 2-2 in Volume II of this report.

2.1.4 Task-Skill Requirement Identification

A task-skill is, in effect, a brief phrase or description which denotes a specific equipment or procedure-oriented crew function. It is derived from the identified primary task dependency and primary crew function, within the context of the experiment and task. Figure 2-2 illustrates the manner in which task-skill titles are formulated. In most instances, the "level #3" task dependency (see Figure 2-1) is incorporated in the task-skill title, but this is not a hard and fast rule. Task-skills can be defined at any level which can be supported by the input data. Very preliminary definition can take place even before the specific types of equipment involved in a task are identifiable. Later, as the experiment becomes better defined, more specific task-skill titles can be substituted. When specific types of equipment or other interfaces are identifiable, these become the level of definition of the task-skill. The task-skill should be identified at the lowest level which will incorporate the essence of the demands of the equipment item (or other factor) and the function to be performed on the knowledge, experience and training of the crewman. If this rule of thumb is followed, the task-skill title will generally be self-defining and will not require the preparation of separate explanatory descriptions.

Figure 2-1: Example of Task Dependency Reference List (TDRL)

LEVEL #1
LEVEL #2

1. System and Facilities
   - A. RAM
   - B. Orbiter
   - C. Booster
   - D. Ground Control
   - E. Satellite
   - F. Space Station
2. Experiment Materials and Equipment
   - A. Observation Equipment
   - B. Control/Display Equipment
   - C. Experiment Materials
   - D. Materials Control Equipment
   - E. Accessory Equipment
   - F. Experiment Records & Data
   - G. Internal Spacecraft Systems
3. Object or Area Under Investigation
   - A. Solar
   - B. Stellar
   - C. Earth Surface
   - D. Man-Biological/Physiological Aspects
   - E. Spacecraft (Physical & Structural)
   - F. Extravehicular Space Environment
   - G. Planetary
   - H. Lunar
   - I. Processes in Zero Gravity
   - J. Processes in Vacuum
   - K. Communication Processes & Equipment
   - L. Navigation Processes & Equipment
   - M. Teleoperations
   - N. Life Support & Habitability Systems
   - O. Man-Performance Capability Aspects
4. Support Equipment
   - A. Communications Equipment
   - B. Data Processing Equipment
   - C. Test and Checkout Equipment
   - D. Miscellaneous Support Equipment
   - E. Life Support & Protective Equipment
   - F. Subsatellites
5. Environment
   - A. Acceleration and Gravity
   - B. Illumination
   - C. Pressure
   - D. Temperature
   - E. Noise
   - F. Radiation (Ionizing)
   - G. Radiation (Radio Frequency)
   - H. Extravehicular Environment (B + C + D ± [F + G])
   - I. Earth Atmosphere
   - J. Fire and/or Explosion Hazard
   - K. Intravehicular Activity Environment (B + C + D)
   - L. Object/Vehicle Relationship

LEVEL #3

(2.A. Observation Equipment)

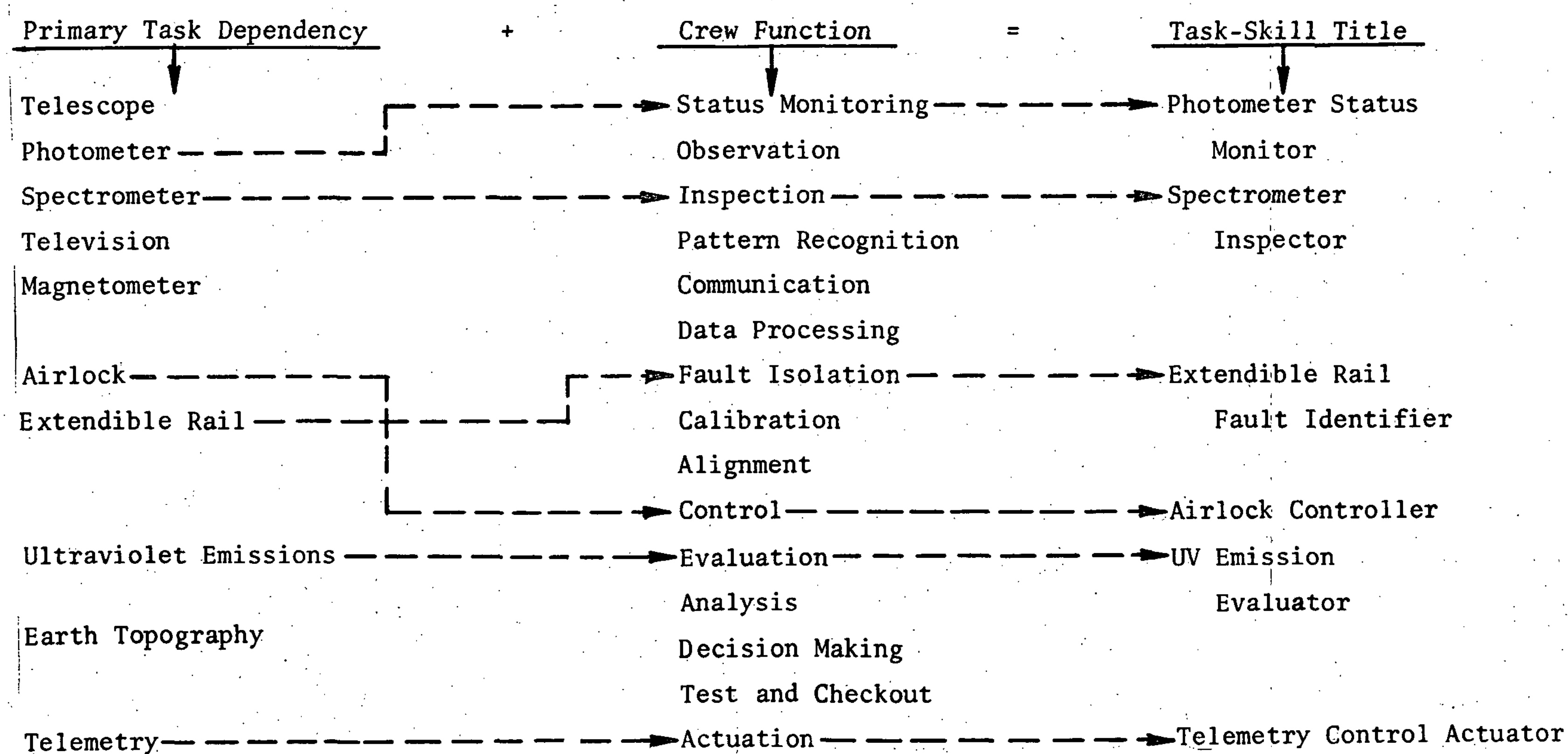
01 Telescopes
02 Photometers
03 Spectrometers
04 Television
05 Image Tube Optical Systems
06 Gas Temperature Chambers
07 Ion Traps
08 Probes
09 Magnetometers
10 VLF Sensors
11 Particle and Meteoroid Sensors/Analyzers
12 Transmitter/Receivers/Antennas
13 Molecular Beam Scattering Device
14 Optical Gratings
15 Band Filters
16 Gas-Surface Interaction Device
17 Film Cameras
18 Microscopes
↓
52 Attitude Measuring Equipment

(4.C. Test and Checkout Equipment)

01 Calibration Equipment And Materials
02 Electrical And Electronic Equipment Test Equipment
03 Laser Transmitter/Receiver Test Equipment
04 Radar Transmitter/Receiver Test Equipment
05 Radio Transmitter/Receiver Test Equipment
06 Millimeter Wave Transmitter/Receiver Test Equipment
07 *Optical Equipment Test Equipment*

	LEVEL #4	TDR CODE
-1	Michelson Infrared Interferometer Spectrometer	2.A.03-1
-2	75 cm Scanning Grating Spectrometer	2.A.03-2
-3	Grazing Incidence EVA Spectrometer	2.A.03-3
-4	Open Source Mass Spectrometer	2.A.03-4
-5	Closed Source Mass Spectrometer	2.A.03-5
-6	Ion Mass Spectrometer	2.A.03-6
-7	EVA Spectrometer (Type Unspecified)	2.A.03-7
-8	Scanning Spectrometer (Type Unspecified)	2.A.03-8
-9	Infrared (I.R.) Spectrometer (Type Unspecified)	2.A.03-9
-10	Ultraviolet (U.V.) Spectrometer (Type Unspecified)	2.A.03-10
-11	Mass Scanning Spectrometer	2.A.03-11
-12	Mass Spectrometer (Type Unspecified)	2.A.03-12
-13	Multispectral Spectrometer	2.A.03-13
-14	Aeronomy Spectrometer	2.A.03-14
-15	Absorption Spectrometer	2.A.03-15
-1	Field Cameras	2.A.17-1
-2	Spectrograph Cameras	2.A.17-2
-3	Metric Camera	2.A.17-3
-4	Multispectral Camera	2.A.17-4
-5	16 mm Time-Lapse Movie Camera	2.A.17-5
-6	Stellar Camera	2.A.17-6
-7	16 mm Movie Camera	2.A.17-7
-1	Optical Spectrometer Calibration Lamps	4.C.01-1
-2	Mass Spectrometer Calibration Gases	4.C.01-2
-3	Gas Chromatograph Calibration Gases	4.C.01-3
-1	Oscilloscopes	4.C.02-1
-2	Digital Multimeters	4.C.02-2
-3	Function Generators	4.C.02-3

Figure 2-2: Task-Skill Requirements Identification Methodology



2.1.5 Occupational Skills

An important feature of the Task-Skill concept discussed in the preceding paragraphs is the development of a method by which the skill requirement identification at the task level could be realistically equated to the source of these skills for specific missions, i.e., the scientists, engineers, and technicians who will ultimately be needed to perform the on-orbit activities. An initial premise was that requirements for experiment or mission-specific training should be held to a minimum and that the experiment crew would be selected from the scientific and technical population to provide the best "fit" to the required task skills. Various methods of job skill and occupational skill definitions were evaluated, including those presently in use by the military services. As a result of those evaluations, it was decided that the broadest, most easily applied method was that being utilized by the U.S. Department of Labor. This method is described in detail in the two volume Dictionary of Occupational Titles (ref. 16) issued by the Manpower Administration of the Labor Department. The Dictionary contains titles and definitions of 21,741 separate occupations, plus 13,809 additional, or alternate, titles for those occupations. It is estimated that the occupational group definitions in the Dictionary will encompass greater than 90% of the required on-orbit research and applications skills, and the method will be applicable to all skill requirements.

2.2 ANALYSIS OF SELECTED FLIGHT EXPERIMENTS

Objectives of the Development of Flight Experiment Task Requirements Study included development of a feasible method for the determination of skills required by on-orbit crew personnel for the conduct of experiments, the development of a data base of task requirements for these personnel, and definitions of the skills required for selected Shuttle flight experiments. The methodology developed to determine skill requirements is summarized in paragraph 2.1 and is described fully in Volume II of this report. This section summarizes the application of the method to a selection of projected experiments.

2.2.1 Criteria for Analysis

An in-depth review of the available experiment/mission descriptions was conducted to determine which experiment activities could reasonably be incorporated into this study that would also provide a representative cross section of typical experiment activities and, subsequently, skill requirements. As the review progressed and new source data emerged, mission options and proposed combinations of experiments became quite numerous and complex.

For purposes of selecting flight experiments to subject to the task-skills analysis, four criteria were defined:

(1) Experiments should be sufficiently well-defined in the experiment descriptions to permit effective application of the Task-Skill Requirement Identification technique;

(2) Experiments should be selected to provide a cross section of research and application activities in all disciplines described in the "Blue Book" (ref. 1) program;

(3) Experiments should be selected to provide a cross section of feasible Shuttle mission modes;

(4) Experiments should be selected so as to permit a wide range of feasible combinations of experiments for Shuttle payloads.

2.2.2 Mission Mode Analysis

An in-depth analysis of acceptable mission modes and experiment combinations for each projected payload was conducted. Reference documents were compared for data on the combinations of experiments which could be considered acceptable in one or more of the primary mission modes. The total number of such combinations was extensive and varied in nature.

Four mission modes were identified as potentially feasible; these are listed and defined in Table 2-2. All FPEs and subgroups identified in each of the three primary reference documents (refs. 1, 2, and 3) were evaluated as to their acceptability in each mission mode. In most cases, fairly good agreement between these source documents was evident.

This mission mode analysis covered twenty-five (25) Functional Program Elements (FPEs) and sixty-nine (69) subgroups in seven (7) scientific and technical disciplines. Also included in the analysis were twenty-seven (27) experiment packages that were identifiable neither as FPEs nor subgroups across the seven disciplines.

2.2.3 FPEs/Subgroups for Detailed Analysis

Having determined the extent of acceptability of each of the FPEs and subgroups for each of the mission modes, identification was made of those which were potential candidates for inclusion in this study. Since Space Station specific activities were beyond the scope of this program, any FPE or subgroup which must be orbited as Mode C was eliminated from further consideration. Where choices existed (e.g., Modes A-5, A-30, B), one or more of these modes was selected as feasible for coverage in the study. Where possible, the selection was made based on the mode most likely to be specified eventually by NASA for the particular FPE or subgroup.

The feasible experiments were evaluated against the selection criteria specified initially (see paragraph 2.2.1). Based on this evaluation of the "most representative cross section" of experiments and on consultation with NASA representatives, some FPEs and subgroups were deleted from further consideration during this study. The FPEs and subgroups identified for additional detailed analysis are listed in Table 2-3 and depict the mission mode selected in each case. Inspection of Table 2-3 indicates that a representative cross section of mission modes, disciplines, and experiments has been achieved. The resulting candidates for detailed analysis include at

TABLE 2-2: IDENTIFICATION OF FEASIBLE RESEARCH AND APPLICATION PROGRAM MISSION MODES

(Based on Reference 1)

MODE DESIGNATOR	MODE DESCRIPTION
A-5	Shuttle-sortie mission with duration limited to five (5) days on orbit. Experiment equipment may be palletized in Shuttle cargo bay, or housed in an experiment module within cargo bay. Experiment operations may be automatic, remotely controlled, semi-automatic, or man-in-the-loop. The experiment module remains attached to the Shuttle at all times while manned.
A-30	Same as A-5, except that on-orbit duration may be up to thirty (30) days.
B	Shuttle-supported free flyer. Experiment modules are delivered to orbit by Shuttle and are made ready for operations by Shuttle-transported crew. Module is left in orbit for extended durations; experiment operations are either automatic or remotely controlled. Module will be periodically revisited by the Shuttle for servicing, maintenance, refurbishment, etc. Total orbital stay time may be up to ten (10) years, with scheduled revisits at six (6) month to two (2) year intervals.
C	Experiment Operations integral to permanent orbiting Space Station, or in modules attached to or in near proximity to the Space Station. The Shuttle will be primarily utilized for initial delivery and subsequent resupply.

TABLE 2-3: FPEs/SUBGROUPS SELECTED FOR DETAILED ANALYSIS

No.	FPE/SUBGROUP TITLE	MISSION MODE A-5	A-30	B
A-4	Intermediate Size UV Telescopes	X		
A-4A	0.9 M. Narrow Field UV Telescopes	X		
A-4B	0.3 M. Wide Field UV Telescopes	X		
P-1	Space Physics Research Lab			X
P-1A	Atmospheric and Magnetospheric Sciences			X
P-1B	Cometary Physics			X
P-1C	Meteoroid Science (Excludes TMMPD)			X
P-1D	Thick Material Meteoroid Penetration (TMMPD)			X
P-1E	Small Astronomy Telescopes			X
P-4	Physics and Chemistry Lab	X		
P-4A	Airlock and Boom Experiments	X		
P-4B	Flame Chemistry and Laser Experiments	X		
ES-1	Earth Observations Facility	*	*	*
ES-1A	Meteorological and Atmospheric Sciences		X	
ES-1B	Land Use Mapping			X
ES-1C	Air and Water Pollution		X	
ES-1D	Resource Recognition			X
ES-1E	Natural Disaster Assessment		X	
ES-1F	Ocean Resources		X	
C/N-1	Communication/Navigation Research Laboratory (CNRL)	*	*	*
C/N-1A	Comm/Nav Research Lab I (Experiments #1-#7)		X	
C/N-1B	Comm/Nav Research Lab II (Experiments #1-#7, #12, #13)			X
MS-1	Materials Science and Manufacturing		X	
MS-1IA	5-Day Group - Biological	X		
MS-1IB	5-Day Group - Levitation	X		
MS-1IC	5-Day Group - Furnace	X		
MS-1ID	5-Day Group - Small and Low Temperature	X		
MS-1IIA	30-Day Group - Biological		X	
MS-1IIB	30-Day Group - Levitation		X	
MS-1IIC	30-Day Group - Furnace		X	
LS-1	Medical Research Facility	*	*	*
LS-6	Life Support and Protective Systems	*	*	*
LS-SH/A	5-Day Life Science Facility	X		
T-5	Teleoperations	*	*	*
T-5A	Initial Flight	X		
T-5B	Functional Manipulation	X		

Legend:
- A-5 - 5 day on-orbit Shuttle Sortie mission
- A-30 - 30 day on-orbit Shuttle Sortie mission
- B - Extended duration, Shuttle-serviced free flyer
- X - FPE/Subgroup to be analyzed for this mission mode
- * - FPE analyzed only to the extent required for analysis of subgroups

least one FPE and/or subgroup from each of the seven (7) disciplines. In addition, at least two FPE subgroups were identified for each of the three potential mission modes (i.e., 5-day Shuttle-sortie [A-5], 30 day Shuttle-sortie [A-30], and Shuttle servicing missions [B]). In one case (Comm/Nav, C/N-1), it was decided to analyze a group of experiments in both the Shuttle-sortie and servicing modes in order to point up differences in skill requirements when orbiting crewmen participate in experiment conduct as opposed to those times when they do not.

2.2.4 Task-Skill Requirements Analysis Results

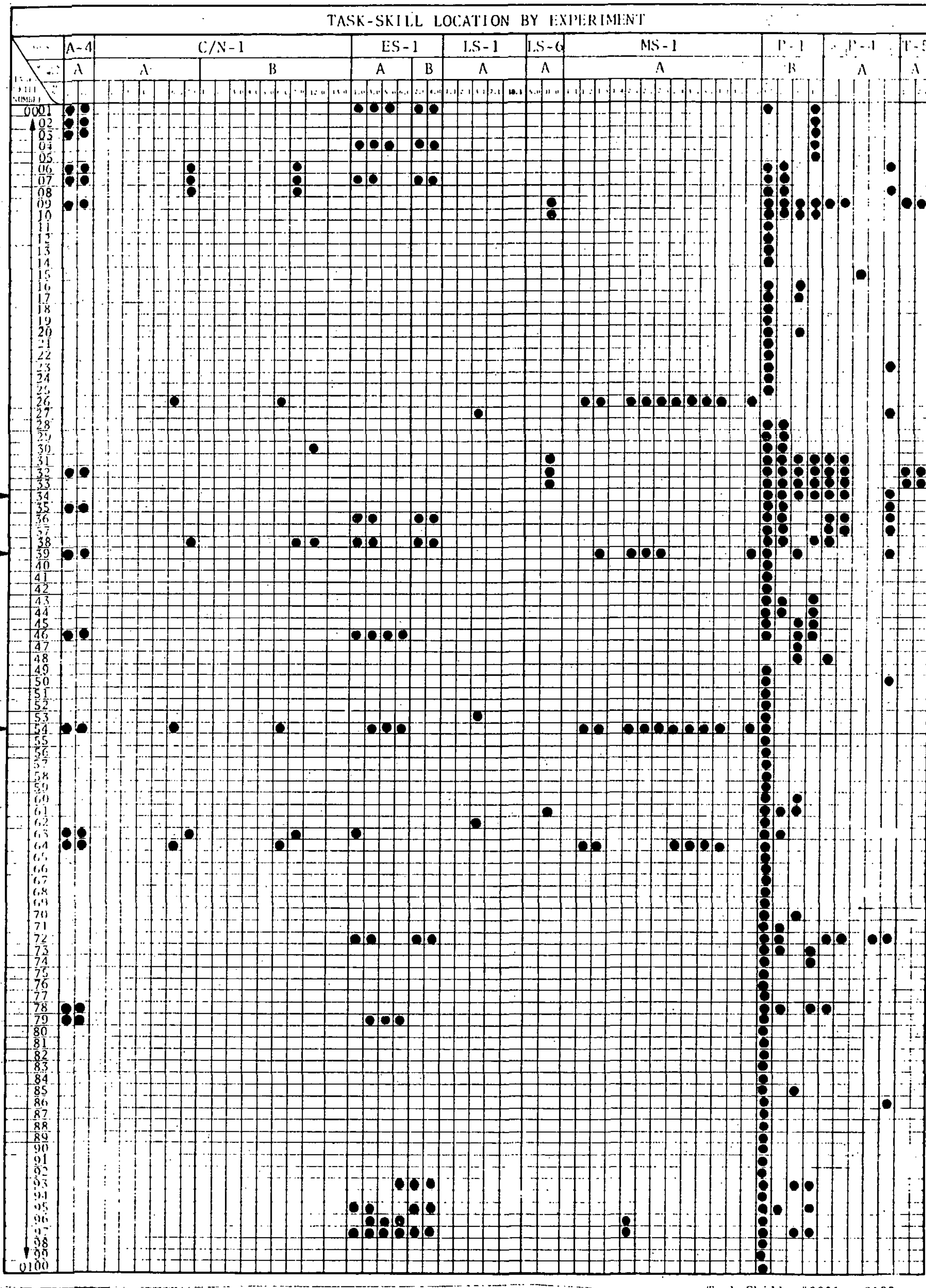
An initial thrust and purpose of this study was to determine the kinds of skills that would be required of on-orbit personnel in support of a research and application program. In order to determine the skills that would be required, the activities, functions, and tasks generating the requirements for particular skills were analyzed, and the skills were defined in such a way that they were independent of the connotations and associations of standard occupational and professional titles. Further, the skills were defined at such a level as to be independent of factors such as crew-size, mission duration, experiment grouping within the payload, or facility characteristics.

Experiment descriptions and supporting data for the selected experiments were carefully analyzed and reduced to a listing of task statements which a crewman may be called upon to perform. For each task statement, the appropriate crew functions, operating environments, and task dependencies were determined. The alphanumeric code numbers for these factors, together with the task statements, were compiled on Task-Skill Data Sheets. Within each task statement, each combination of crew function, operating environment, and primary task dependency resulted in the determination of a task-skill requirement. As explained in the preceding paragraphs, a task-skill title is a brief phrase which denotes a specific crew function performed relative to a specific item of equipment, a specified procedure, or an area of investigation or knowledge. The task-skill is derived from the primary task dependency and the crew function within the context of the experiment and task. Task-skill titles (and code numbers) were compiled in the Task-Skill Data Sheets with the task statements generating the requirement. (See Volume II, Appendix H for data sheets for all experiments included in this study.)

The analyses conducted in this study resulted in the identification of 2,044 separate task-skills required for the forty-eight experiments encompassed by the study. A complete listing, in numerical order, of the identified task-skill titles is included as Appendix E to Volume II of this report.

In addition to the compilation of task and task-skill information in the data sheets, it was of interest to determine the extent of task-skill commonality across different experiments, both within an FPE and across different disciplines. A preliminary evaluation was conducted to identify the frequency of occurrence of task-skill titles in different experiments and the results of this evaluation are compiled in Appendix F of Volume II of this report. No attempt at statistical analysis was made. Figure 2-3 illustrates the manner of compiling this commonality data and shows the wide

Figure 2-3: Example of Task-Skill Commonality to Experiments



range of frequencies of task-skill location in experiments, from single experiment occurrence (#0015), to multiexperiment occurrence within an FPE (#0016), to multi-FPE occurrence within a discipline (#0034), to multidiscipline occurrence (#0039 and #0054).

2.2.5 Conversion of Task-Skills to Occupational Skills

Preliminary trade-off analyses were conducted to arrive at a feasible method for obtaining the needed skills through specification of appropriate occupational skill categories. Factors such as performance effectiveness, acquisition lead time, availability, cost, and the number and criticality of the task-skills encompassed by the occupational skill were considered. It was decided that the broadest, most easily applied method was that being utilized by the U.S. Department of Labor. This method is described in detail in the two volume Dictionary of Occupational Titles (ref. 16) issued by the Manpower Administration of the Labor Department and is discussed in Volume II of this report.

It was beyond the scope of the present study to conduct the analyses which would group the identified task-skills into one or more occupational skills. A preliminary evaluation was made, however, to ensure that the method selected would, in fact, be suitable. It is estimated that approximately 90% of identified task-skills are convertible to occupational skill classification.

Application of this method in subsequent programs will provide identification of the scientific, engineering, and technical skill requirements for all experiment/mission combinations which can be satisfied through selection of candidates from the general population, by specialized training, or by assignment to available personnel.

2.3 SCIENTIFIC INTUITION VERSUS PLANNED EXPERIMENTATION

Some questions frequently raised during discussions and briefings regarding this study were, in essence, "Should we really be concerned with trying to determine skill requirements and assigning tasks for the conduct of research by scientists? Aren't most scientific discoveries the result of intuition and opportunistic experimentation rather than preplanned procedural investigations?" Certainly such questions have merit and deserve consideration, but the answer to them lies somewhere in between a simple yes or no. It would be as fallacious to subscribe to the romanticized idea of the scientist, working alone amoung the clutter of his laboratory, suddenly "happening" upon the answer to some as yet undefined problem as it would be to remove all opportunity for the on-orbit researcher to respond to unforeseen and unusual scientific occurrences and events. The fact is that most major discoveries of modern science have been the result of carefully planned, painstakingly carried out, experimental procedures. The scientists of today, however brilliant, generally depend on a wide variety of personnel and equipment resources for support in achieving their successes. The senior scientist in such a team not only makes the major decisions and contributes his own skills and knowledge to the project but also draws on the knowledge and capabilities of other team members (or outsiders) to accomplish those things of which he is either not capable or for which he is not available. This, then, is the philosophy behind the effort to determine skill requirements for on-orbit research. The intent is not to provide a basis for selecting a senior scientist to go on the mission but, rather, to determine the performance requirements for the total crew complement. The skills, knowledge, and capabilities of each member must be complementary and appropriate to the mission. Mission duration, number of personnel, and availability of other resources will be too limited, and expenses associated with placing the payload in orbit will be too great, to trust to scientific intuition alone.

2.4 SUMMARY OF ACTIVITIES AND ACHIEVEMENTS

The following items represent the more significant activities and achievements attained during the performance of this study:

- Development of a comprehensive listing of items and factors upon which successful performance of crew functions in each experiment task depends -- the Task Dependency Reference List.

- Development of a methodology to permit identification of the skills required in the performance of on-orbit experimentation and payload servicing -- the Task-Skill Requirements Identification system.

- Identification of the task-skills required in support of the representative cross section of forty-eight experiments in the Reference Earth Orbital Research and Application Program.

- Development of a methodology to relate task-skill requirements to occupational/professional skill classifications for eventual selection and/or training of required on-orbit experiment personnel.

- Construction of a comprehensive data base of functions, crew functions, operating environments, task dependencies, and task-skills applicable to a representative cross section of earth orbital research experiments.

3.0 CONCLUSIONS

The analyses and investigations conducted during the course of this study, and the results obtained, lead to the following conclusions:

a. It is feasible to identify skills required of crew members early in the definition phase of development programs. It is neither necessary nor appropriate to wait for complete definition of equipment, facilities, or objectives prior to initiating a skill requirements analysis.

b. Assessment of skill requirements must be based on an objective evaluation of the activities and tasks which personnel may be required to perform. The assessment should be at as detailed a level as is possible considering the status of program definition. Subjective evaluations which result in instant "skill requirement" specification should be avoided. Too often this practice has been followed in experiment definition studies, and the evaluator has based his skill requirement specification on what the experiment seems to require in the way of personnel support because of the nature of the objectives of a group of experiments. Such an approach is invalid, and it can be misleading to mission planners.

c. Determination of skill requirements at the elemental level (i.e., task-skills) will permit crew complements to be partially structured as a direct output of timeline analysis. This is true since each element in a detailed timeline analysis will have one or more identified task-skills associated with it. Appropriate use of automatic data processing and sorting methods will provide immediate identification of conflicts between requirements for and availability of specified skills.

d. There appears to be a tendency on the part of experiment definition personnel to emphasize the requirements for scientific skills at the expense of technical skill requirements. The validity of such emphasis cannot be confirmed until the process of combining task-skills into occupational skill groups has been completed, and it may simply be an artifact of the skills data compilation. Certainly, much will depend on the finalized configuration and operating philosophy, as well as the maintenance and repair philosophy, for each experiment in each payload.

e. A method is available for utilization of skill requirements information as an aid to experiment and mission planners in making decisions regarding payload content, configurations, policy, procedures, and objectives. It is hoped that this method will be widely utilized in concert with other valid decision criteria, since man's flexibility as a system element, while broad, is not limitless.

4.0 POTENTIAL APPLICATIONS OF TASK-SKILL METHODOLOGY AND DATA

The study documented in this report has achieved the objectives of developing a useful skill identification methodology and establishing a data base of skill and skill-related information. As such, it can be said to represent a satisfactory return to NASA for the resources invested. The true worth of the study, however, will have to be measured by the extent of usefulness in future activities. The potential applications of the methods and data comprising the output of the study lie in three areas:

a. Utilization of data and methods in work in progress;

b. Utilization of data and methods in currently planned and projected NASA programs;

c. Utilization of methods in non-NASA programs and activities.

4.1 APPLICATIONS TO WORK IN PROGRESS

The data base and the methodology developed in this study are being applied to a new contract, Definition of Flight Experiment Work Performance and Workstation Interface Requirements (NAS8-28359). Study in the area of that contract is aimed toward establishing the scientific and technical task performance capability requirements for a number of NASA-selected early Shuttle-sortie missions, determining requirements for experiment accommodation and performance on the basis of scientific and technical crew capabilities and task loading, and defining experimenter interface concepts for several NASA-selected workstations.

The task-skill/task dependency data base will be updated to include those experiments not covered in the current study and to incorporate the latest experiment definition data, using the methodology developed herein. Task-skills will be converted to occupational/professional skill classifications for each projected experiment payload, and the feasibility of achieving suitable crew complements based on skill-mix will be determined. For those determined to be feasible, task sequences and timelines will be prepared, and determination will be made of experiment payload feasibility on the basis of task loading and the availability of the on-board crew capabilities at the time and place they are needed. NASA will select several of these feasible experiment payloads for definition of experimenter workstation concepts that best satisfy the interface requirements and complement the skills available as determined in the preceding analytical tasks. Deriving from the completed efforts of this new study will be:

- A broadened task-skills data base for Reference Experiment Plan (REP) missions.
- Detailed functional and task sequence flow charts for NASA selected early Shuttle missions.
- A detailed listing of equipment and instrumentation required for conduct of priority orbital research experiments and their associated performance capability requirements.
- A detailed listing of scientific crew performance capability requirements for conduct of selected orbital research experiments.
- A detailed listing of experiment/mission combinations for early Shuttle missions which are feasible for accomplishment by the allotted number of flight experiment crewmen having the required scientific and technical capabilities.
- A detailed listing of selected experiment/mission combinations for early Shuttle missions which are feasible for accomplishment within the time limits imposed on the mission, with due consideration of flight experiment crew taskload and duty cycle limitations.
- Preliminary design concepts for two (2) orbital research workstations which reflect all of the above considerations.

4.2 APPLICATIONS TO CURRENTLY PLANNED AND PROJECTED NASA PROGRAMS

The methodology which has been developed in this study and, to a great extent, the data base which has been established have potential for utilization in a wide variety of programs currently being planned and/or defined by NASA. Two categories of application are anticipated: determination of skill requirements and solution of skill-related problems.

4.2.1 Skill Requirements Analysis

Both the task-skill identification methodology, as described in this report, and the data base which has been established have direct applicability to a wide range of projected NASA programs. With little or no change, they can be utilized to determine on-orbit experiment crew skill requirements for Shuttle-sortie module and palletized experiment missions. They are equally applicable to the experiment setup and servicing tasks associated with Research and Application Module (RAM) free flyer experiment missions and, eventually, for experiment related activities in a permanent orbiting Space Station. The experiment crew responsibilities and tasks in all these mission types are sufficiently similar to those analyzed in the current study that analysis of each mission would be a process of building on what has been accomplished rather than starting in a new direction.

The technique used for task-skill analysis would be equally appropriate for determination of skill requirements for ground operations to support spaceflight. This would include ground checkout, launch control, maintenance, repair, and refurbishment of both flight systems and ground systems. The established data base, of course, would be less appropriate for this kind of application. The technique may also be valid for skill requirements determination with regard to space vehicle flight crew activities, i.e., the tasks of piloting, command, navigation, etc. It is, however, probably less appropriate in this application, since all anticipated flights will involve a fairly specialized flight crew population and will, for safety reasons, require lengthy and vehicle-specific training.

4.2.2 Skill-related Applications

The task-skill data base and methodology can also be applied to areas related to, or dependent on, the skills possessed by flight crews, experiment crews, and/or ground crews. As is projected for accomplishment in contract NAS8-28359 (see paragraph 4.1), analyses of task loading for assigned crew members can be conducted to determine how much work is being assigned to each skill area (and, thus, to each crew member) and how long a given task will require those particular skills. Similarly, timeline analyses for individual skills (and, thus, each crew member) and for various sizes and structurings of crew complements can be used to determine optimum task sequencing, crew interactions, overlapping of task demands on crew skills, etc. Analyses and investigations of the interfaces between crew members and the equipment they must utilize and/or accommodate can be accomplished through the use of the Task Dependency Reference List (TDRL). This systematized listing (see paragraph 2.1) can be specific to individual controls, displays, modules, etc., through the addition of further "levels" in the task dependency categorization.

4.3 APPLICATIONS TO PROGRAMS OUTSIDE OF NASA

The methodology developed in this study has potential for effective utilization in a wide variety of program areas outside of NASA, including military, other nonmilitary government, and private/civilian applications. As in the NASA programs described above, the technique is valid for determination of skill requirements, conduct of task loading and timeline analyses, and performance of crew to crew and crew to equipment interface analyses, when the object systems/programs meet certain general criteria. Programs can be considered as meeting these criteria when:

- advance personnel resource planning is required, and
- the personnel resource requirements will be complex, or
- the personnel resource requirements will be critical, and
- lead time or total time available for personnel training is limited.

Examples of programs or development activities which will generally meet these conditions, especially if new plans are undergoing definition or if substantial additions to (or revisions of) existing programs are being contemplated, are as follows:

a) Hospitals -- Staffing requirements will include medical services, administration, maintenance of facilities and equipment, laboratories, laundries, food service, custodial service, etc.

b) Airports -- Personnel resource planning must anticipate the needs of administration, tower, scheduling of arrivals/departures, facility and equipment maintenance, and support (parking, custodial) services, etc. Greater integration with carrier-supplied personnel resources is also possible. Other transportation terminals (e.g., train, bus, and ship) have much the same problems and are equally appropriate for consideration.

c) Hotels -- Individual hotels and hotel chains can be operated more efficiently (and therefore more profitably) with thorough advance planning for personnel resource requirements in administration, maintenance, restaurants, laundries, patron services, and support services.

d) Manufacturing -- Plans for establishing or substantially revising manufacturing facilities, especially production lines for new products, should anticipate the associated personnel resource requirements. New products, or new equipment utilized in the manufacture of older products, may require new skills or skills in short supply in the local area. Consideration should also be given to preparing skill inventories of all existing employees and matching them with the skill requirements of the various jobs. Indications are that employee motivation is increased when the employees' job assignments utilize a broader range of the skills they possess, even when this includes some degree of rotation around a selection of job assignments. For example, performing a series of tasks or operations in the building of a product is more satisfying than the repetitive performance of a single operation.

e) Building Construction -- Builders of large and complex projects should reexamine the actual skill requirement of construction projects separately from the availability of traditional building trades. As with production line assignment changes (paragraph "d", above), wider utilization of available skills may improve motivation and establish a more cohesive worker group. Assuming that appropriate changes could be negotiated with the building trades unions, greater efficiencies and lower costs may be realized by eliminating delays due to interunion disputes over job assignments or to the temporary unavailability of the "correct" building trades personnel.

5.0 SELECTED REFERENCES

The following publications are those which have been referred to in this volume of the Final Report. A complete list of reference materials utilized during the course of this study is included as Appendix A to Volume II of the report.

1. NASA: Preliminary Edition of Reference Earth Orbital Research and Applications Investigations (Blue Book), Jan. 15, 1971.

    Vol. I Summary
    Vol. II Astronomy
    Vol. III Physics
    Vol. IV Earth Observations
    Vol. V Communications/Navigation
    Vol. VI Materials Science and Manufacturing
    Vol. VII Technology
    Vol. VIII Life Sciences

2. Martin Marietta Corp.: Experiment Requirements Summary for Modular Station and Space Shuttle Orbital Applications and Requirements (Green Book), Rev. 1, Martin Marietta Denver Div., Denver, Colo., April 28, 1971.

    Vol. I Introduction; FPE Descriptions and Envelope Drawings; FPE Requirements Summaries
    Vol. II FPE Subgroup Requirements

3. NASA Marshall Space Flight Center: Task II Output of MSFC In-House Study, Second Edition, NASA, Huntsville, Ala., March 1971.

16. U.S. Department of Labor: Dictionary of Occupational Titles, Third Edition, Washington, D.C., 1965.

    Vol. I Definition of Titles
    Vol. II Occupational Classification and Industry Index