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INTERFACE PROBLEMS IN SPACE EXPERIMENTATION

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by

R. F. Filipowsky
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INTERNATIONAL BUSINESS MACHINES CORPORATION

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ABSTRACT

Space experimentation is expanding rapidly. Unmanned satellites are being equipped with precision instruments of greater power, and manned space stations accommodating large crews are in the drawing-board stage. The interface problems between these sophisticated instruments and between man, the spacecraft, and the supporting ground stations are multidimensional. This paper analyzes the scientific/technical areas of space experimentation, and continues with a review of the subsystems and support systems required to supply and operate the large variety of instruments. Areas of major integration efforts are singled out and the requirements for further developments and improvements are listed. A bibliography of 95 references is enclosed to assist in the identification of more detailed reports on all vital aspects of space experimentation.

INTRODUCTION

During the second decade of space exploration, spacecraft will probably follow a general purpose design in contrast to the special purpose designs which were used in the past. Formerly, the mission (i.e., the purpose of the spacecraft) was the starting point. Subsystem design and integration efforts were concentrated on the problem of serving this well-defined mission with a minimum consumption of weight, space, and electrical energy. This situation changed with the arrival of orbiting observatories where, from the outset, the over-all scientific mission area is known but unknown is the complete experiment plan. Increased flexibility in accommodating a large variety of experiments is demanded. Many of these experiments may undergo considerable modifications during the lifetime of the program; some will be unknown prior to the first flights. Therefore, the spacecraft's subsystems must be designed to meet a wide range of demands.

Manned laboratories' planning and Apollo Applications Project requirements increased the interface problem between experiments (sensors) and subsystems. Man's capability to control and modify subsystems can now be used. Supervisory devices and controls for the experiments are now essential within the spacecraft; however, full monitoring capability in the ground station must be retained. Also, increased payload capability of Saturn boosters removes most restrictions on weight and many restrictions on the size of instruments which can be used in advanced space experiments. An unexpectedly large number of smaller experiments can be accommodated easily.

The ensuing integration task is to sizeable proportions and is generally known as payload integration. It has to cope with:

a) multidimensional interfaces between the experiments and spacecraft subsystems,
b) instruments in space and corresponding instruments on the ground,
c) related, usually unmanned flights and manned experiments to be integrated; and
d) man, his instruments, and space environment.

The first part of this paper describes scientific technical areas which will require space experimentation during the next decade. The second part describes the subsystems and auxiliary systems and auxiliary systems necessary to support this vast area of experimentation. A companion paper* delineates the organization of payload integration efforts and shows a number of graphical and computorial aids which can be applied to facilitate the payload integration task.

No specific space program is used as the basis for this paper; however, it is natural to consider the Apollo Applications Project as the United States' space project presently having the strongest demands for experiment payload integration. Some of the flights will require the continuation of experiments in unmanned parts of the spacecraft long after man has returned to earth in a special reentry module. Thus, in this case, the integration task has to consider the manned, and unmanned phases independently. The experience in payload integration gained from the AAP will be beneficial for the experiment integration of unmanned spacecraft.

LIST OF ABBREVIATIONS

AAP	Apollo Applications Program
AMU	Astronauts Maneuvering Unit
APU	Auxiliary Power Supply Unit
ATS	Applications Technology Satellite
ESP	Extra Sensory Perception
EVA	Extra Vehicular Activity
EVEA	Extra Vehicular Engineering Activity
FOV	Field of View
IMP	Interplanetary Monitoring Platform
LEM	Lunar Excursion Module
MORL	Manned Orbiting Research Laboratory
OAO	Orbiting Astronomical Observatory
OGO	Orbiting Geophysical Observatory
OSO	Orbiting Solar Observatory
OSSA	Office of Space Science and Applications (NASA)
OTS	Optical Technology Satellite
POGO	Polar Orbiting Geophysical Observatory
RADA	Random Access Discrete Address System (U. S. Army)
SMS	Small Maneuverable Satellite
STA	Scientific/Technical Area
SST	Supersonic Transport Aircraft

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*Green, P. C., and Filipowsky, R. F. "Payload Integration for Space Experimentation." Paper submitted for presentation at the same symposium (Seattle, July 1966; see pp. of these proceedings.)

PART 1. SPACE EXPERIMENTATION

Civilian spacecraft applications are in the experimental stage, though it is gratifying to note that in the communications and weather observation areas, the first operational systems are available. In the next decade, space experimentation will continue to be the principal objective of most space flights and will cover seven major areas and many subareas, designated STA (scientific/technical area). Figure 1 shows the STAs in their logical order of importance. Flight technology is essential before further space applications can be considered, and improvements will be needed in certain areas of subsystem test in order to meet the requirements of more advanced flight technology. Man's adaptation to space environment, and the continued exploration of this environment, are further essentials for advanced space flight. If these four major areas are promoted successfully, it will be possible to achieve results in: space science investigations, exploration of the solar system, and, finally, space utilization. A description of some of the STA subareas follows.

1.1 Flight Technology.

Further improvement is needed for supersonic aircraft and crafts having the same basic structure, both capable of mastering space and the lower airspace. The development of many spacecraft systems will be important for the design of such advanced aircraft. Conversely, it may be expected that the extreme requirements, imposed on the guidance and navigation subsystem, by such aerospace crafts, will be beneficial to future space missions — a point which should not be overlooked by payload integrators. The crossed circle symbol in Figure 1 indicates this fact by showing the aircraft/guidance field as an "area of major integration effort" with requirements for "special design and development" and with "critical demands" on the present subsystem capabilities. The instrument designers will face a major integration task in connection with monitoring instrumentation, primarily during the development phase of such advanced spacecraft.

Similarly, Figure 1 indicates that:

a) The advance of experimental rockets and balloons will parallel increased design efforts in analysis instrumentation (e.g., spectrometers),

b) Improved antennas and transmitters will be required,

c) Signal conditioning and power supply subsystems are the areas of major integration efforts for the class of space experimentation with rockets and balloons.

Other important developments in flight technology should lead to space boosters with at least the lifting capability of Saturn V, and other improved characteristics. For manned planetary missions of longer duration, a vehicle called "Blockbuster," utilizing both solid and liquid propellant rockets, may be the best approach. It could be available sometime after 1978 [1]. The high energy upper stage or "planetary-kick stage," fueled by fluorine, is close to hardware development [2]. It will be used in conjunction with the Saturn V launch vehicle for unmanned planetary missions. The availability of such improved upper-stage engines offers the possibility of using the second and third stage of the Saturn V as a separate launch vehicle, filling the need for a booster with capabilities between Saturn IB and Saturn V [2]. Reusable boosters and the recovery of expandable boosters have been studied extensively. It is now necessary to gather data regarding the preferred design characteristics. These data will enable decisions to be made regarding the most economical approach [2]. Reentry technology will continue to attract high interest [3, 4]. The necessary experimentation in booster technology will call for improved signal processing systems to handle the vast amount of noisy data. Improved antennas will be needed, specially designed for both boosters with atmospheric maneuverability and reentry vehicles. Advanced guidance and navigation systems, closed-circuit TV systems with high resolution for dangerous observations during test flights, and special airlocks and windows will facilitate the experimentation with such novel boosters.

Spacecraft technology will experience brisk development in the area of manned space stations. The present state of the art is characterized by the Gemini spacecraft [5], the Apollo spacecraft [6] and the Lunar excursion module (LEM) [7]. The next generation of spacecraft will be manned space stations [8] for a crew of 6 to 12 men. The manned orbiting research lab (MORL) is the center of NASA studies. It will use the Saturn boosters and can be designed as a universal type of space laboratory required for all the areas of experimentation listed in Figure 1. The preliminary plans even call for an internal centrifuge providing crew-member therapy and comparative experiments describing long-term influence of gravitation on man's ability to perform in space. Logistics vehicles (space ferries) will be needed to supply space stations because missions from forty-five days to ultimately ten years are under

SCIENTIFIC TECHNICAL AREAS (STA) OF EXPERIMENTATION			INSTRUMENTATION							DATA MANAGEMENT				COMMUNICATION							CONTROL AND DISPLAY			ASTRO-NAUTICAL SYSTEMS			STRUCTURAL SYSTEMS					SUPPORT SUBSYSTEMS				
AREA	SUBAREA	RELATED PROJECTS	SYNOPTIC INSTR.	ANALYSIS INSTR.	MONITORING INSTR.	TRANSAUCERS	SPECIAL BIO INSTR.	GENERAL LAB, INSTR.	SPECIAL EXP. SUBSYST.	SIGNAL CONDITIONING	DATA STORAGE	DATA PROCESSING	SIGNAL PROCESSING	ANTENNAS	TRANSMITTERS	RECEIVERS	VOICE INTERCOM.	INTERNAL DATA DET.	CLOSED CIRCUIT T.V.	ASTRO SURFACE COMM.	LABORATORY CONSOLE	CONTROL CONSOLE	OBSERVATION CONSOLE	GUIDANCE AND NAVIGATION	ATTITUDE CONTROL	SECONDARY PROPULSION	AIRLOCKS AND WINDOWS	EXPANDABLE STRUCT.	SECONDARY STRUCT.	THERMAL SUBSYST.	POINTING SUBSYST.	POWER SUPPLY	INSTRUMENT SUPP.	ELECTRONIC SUPP.	LIFE SUPPORT SYST.	EVEA SUPP. SYST.
FLIGHT TECHNOLOGY	AIRCRAFT	X-15, SST			○	•				•				•	•	•	•				•			Ø								•			•	
	ROCKETS AND BALLOONS	SCOUT, STRATOSCOPE		Ø	•		•		•	○				\•	\•	•											\			•		○	•	•		
	BOOSTERS	RECOVERABLES, HEPKS *			•	○				•	•	•	Ø	\	Ø	X	•	•	\•		•	•		⊗	•		○	•		•		•			•	
	SPACECRAFT, REENTRY VEHICLE	MOPL, M2			•	•		○	○	•	•	•	•	•	•	•	•	•	•		•	•	•	○	○	⦸				•		⊗			⊗	•
FLIGHT SUBSYSTEMS TECHNOLOGY	OPTICAL COMMUNICATIONS	OTS, AAP	Ø		•			X		•			⊙		○	○		•	•	○		•			⊗			•	•	Ø	⊗		○	•		
	ADVANCE APU TECHNOLOGY	SNAP 10A, 11, 19, 27				•		•			•										•			○	○	○				•		○	•	•		
	IMPROVED ONBOARD PROPULSION	•		•	•	•			•		•				•	•		•				•	•											•		
	INFORMATION COMPACTION	•				•				Ø	○	○						Ø			•		○										○	○		
	UNIVERSAL DATA MANAGEMENT	•								○	⊗	○	○																					•		
MAN'S ADAPTATION TO SPACE	ADV. LIFE SUPPORT SYSTEMS	AAP			○		⦸			⦸	•	•					○	⊗	○	○	•						○			○			•	•	Ø	
	EXTRA VEHICULAR ACTIVITIES	GEMINI, AAP, EVEA*				•	○		⊗		•	•		○			○		⊗	○	•	•				⦸	⦸	○	•	○					⊗	⦸
	SPACE MEDICINE AND BEHAVIOR ANAL.	AAP		•	•		○	•						•			○	•	⊗	○			○		•								○	○	○	•
SPACE ENVIRONMENT EXPLORATION	BIOSCIENCES (LIFE DETECTION)	BIOS		⦸	○		○	○		○	•	•					•		⦸	○		○	○				•			○			○	•	⦸	
	ZERO-G PHYSICS	AAP			•	•		⦸	⦸										•		•	•								•		•	○			
	ENVIRONMENTAL PHYSICS	EXPLORERS, PEGASUS		Ø	○					•	○	•		○	•	•				•	•				•		•	○			•	•	○	○		
SPACE SCIENCE INVESTIGATIONS	ASTRONOMY AND ASTROPHYSICS	OAO, AAP, IMP, EXPLORER	Ø	⊗	•					⦸	Ø	Ø	•		•	•		•	•		•	○	○		⊗	⦸			○	⊗	Ø		•	•		•
	ATMOSPHERIC SCIENCES	OGO, AAP SCANNER, ALOUETTE, ISIS, ARIEL	○	○	•					•	○	•		•							•				•		•				•					
	EARTH SCIENCES	AAP, TRANSIT, GEOS	Ø	•						⊗	○	○	⊗	•	•			•	○			○	Ø	○	Ø					•	⊗	○	•	○		
SOLAR SYSTEM EXPLORATION	LUNAR EXPLORATION	RANGER, SNAP 27 SURVEYOR, APOLLO, LUNAR ORBITER	○	○	•		○			○	•	•	○	⦸	Ø	•	⦸		⦸	⊗	•	⦸	○	⊗	•	○	⦸		⦸	⊗		⊗	○	⦸	⊗	⊗
	PLANETARY EXPLORATION	VOYAGER, EXT. PIONEER, MARINER	○	Ø	•		•			⦸	⊗	○	○	○	⊗	•				•	•	•	⊗	⊗	•			•		•	○	⦸	•	•	•	•
	SOLAR EXPLORATION	OSO, PIONEER, AAP, EXPLOR.	•	⊗	○				•						○				○		•	•	○					•		⊗	•	•	•	•		
SPACE UTILIZATION	EARTH RESOURCES STATISTICS	AAP	Ø	○	•					○	Ø	Ø	⊗	⊗	○	○			•		•	○	○	Ø	⊗						○	○	•	Ø		
	WEATHER AND FLOOD OBSERVATIONS	TIROS, NIMBUS	○							○	○	○	•	•	•	•					•	•	•	•	•						○	•				
	COMMUNICATIONS AND NAVIGATION	TELSTAR, RELAY, SYNCOM EARLY BIRD, ATS *		⦸							•	•	⦸	⊗	⦸	⊗				⦸				•	•			⦸	•		•	○				
	SPACE MINING	•	\•	⦸	\•		\•	⦸	\								•	•	○	⦸	•	•	•				⦸	⦸	\	\		\			\	⊗
	SPACE ENVIRONMENT UTILIZATION	•						⊗	X		•	•					•		⦸		•	⊗					⊗		\	⊗		○	⦸		⊗	⦸

*HEPKS = HIGH ENERGY PLANETARY KICK STAGE

• ROUTINE OPERATION (NORMAL DEMAND)

ATS = APPLICATIONS TECHNOLOGY SATELLITE

\ = SPECIAL DESIGN AND DEVELOPMENT CONSIDERATIONS

EVEA = EXTRA VEHICULAR ENGINEERING ACTIVITIES

/ = CRITICAL DEMAND

○ = AREA OF MAJOR INTEGRATION EFFORT

FIGURE I. SCIENTIFIC-TECHNICAL AREAS OF SPACE EXPERIMENTATION consideration. Beyond earth-orbiting space stations, there is the need for planetary landing craft and for roving vehicles to explore the surface of celestial bodies — first of all, the moon [9]. There is no doubt that the universal character of space stations will present formidable integration problems. The design of subsystems must take into account all the requirements for experimentation in most of the STAs of Figure 1. The figure identifies eight areas of major integration efforts (marked by circles). Four of those (i.e., secondary propulsion, airlocks, power supply, and life-support systems) will require new developments to meet the demands of manned space stations. Secondary propulsion and power supply subsystems have to be redesigned for roving vehicles. All these new developments require experimental testing phases in space which, in turn, will be of concern to payload integrators.

1.2 Subsystems Technology

This art has to keep pace with spacecraft technology and the expanded missions of the next decade. Five special subsystem development areas are singled out in Figure 1 as areas which will require extended experimentation in space, and are briefly discussed below. Many other subsystems areas will undergo further development, and some of their problems are mentioned in Part II. However, these developments will be promoted by testing in ground simulators or as back-up systems in space flights, while the following five problem areas depend on special space experimentation, specifically oriented toward a special development goal. This is the reason they are listed as separate subareas of the STA "subsystem technology."

Optical communications is the great hope for interplanetary communications with large bandwidth. This, in turn, is essential to transmit pictures in real time over planetary distances. All calculations show that it is unlikely that radio communications will be able to achieve this goal within the next two decades [10]. Optical communications offers the theoretical possibility of concentrating the transmitted energy into extremely narrow beams of light (pencil beams) of less than one second of solid angle. However, many problems will have to be solved before optical communications over planetary distance may become reality. First of all, it is essential to get reliable data about the propagation of beams of coherent light as they are produced by lasers — the new devices which are the basis of all hopes for optical communications. Absorption in the atmosphere, beam spreading (scattering), rotation of the polarization plane and instabilities (scintillations) are among the characteristics which have to be studied. Little is known about the "optical noise" which presents itself as earth shine, tending to mask the thin beam of man-produced light. Gigantic telescopes will be needed in the spacecraft and on earth, and new optical components (such as filters having a bandwidth only fractions of an Angstrom) are essential. Nothing is known about the performance of such devices when exposed to the space environment for several years. Even when all these problems can be solved, there remains the tremendous operational problem of mutual acquisition of two such pencil beams. Real time computers will help solve the feat of maintaining the two beams mutually locked on their opposite stations with the earth rotating around its axis, and moving around the sun and the spacecraft following its own trajectory and rotating around its three axes a hundred million miles away. Consider that the light will travel for several minutes from one station to the other, presenting a "point-ahead" problem of unbelievable difficulty.

Nevertheless, engineers are confident that all these problems can be solved [11]. Years of experimentation lie ahead with experimenters simulating optical deep-space communications through tests from earth-orbit-to earth-surface or between spacecraft around the earth; and, finally, including stations on the lunar surface. Figure 1 indicates nine areas of major integration efforts in the line of optical communications. New developments are needed in attitude control and pointing systems. Naturally, the development of the special telescopes (under synoptic instruments) will be the principal effort. NASA already has several studies under progress which will better define these experiments for the Apollo Applications Program (AAP) [12] or which are preliminary feasibility investigations of special optical technology satellites (OTS) [11].

The difficulties listed above are typical for many of the following space experimentation areas. The payload integrator has to consider them in full detail. For the purpose of this paper, a few of the areas will be discussed. Figure 1, supplemented by the literature references, will assist the reader.

Auxiliary power supply units (APU) will have to provide electric energy for all experiments and for all subsystems. Major new developments in the areas of fuel cells and nuclear energy sources are in the experimental stage [13]. They will be matched by improvements in power distribution and the sequencing subsystem [14].

On-board propulsion is needed for: a) added maneuverability for docking operations, b) launching or rotating secondary structures in space, c) attitude control, d) planetary landing, e) roving operations, f) launching from celestial bodies, g) injection into return trajectories and h) reentry and landing on earth. Multipurpose propulsion systems will be able to cover simultaneously some of these demands. Special purpose propulsion modes will still prevail for such applications as attitude control and roving operations. Chemical, nuclear, electrical, stored pressure, and subliming solid energy sources will have to be compared in actual space experimentation [15].

Information compaction (also called message compression or redundancy reduction) is an electronic manipulation with sensor outputs, voice waveforms or picture signals with the purpose of preventing unnecessary information from entering the storage devices or the communications channel. Thus, it will be possible to reserve the limited capacity of these subsystems to handle essential information. Typical examples are: a) transmission of changes only, in instrument readings, in place of the frequent repetition of constant readings, b) interruption of voice transmission during gaps in speech, c) avoidance of repeated transmission of still pictures. Complex studies are necessary of the characteristics of information sources and operational comparison of various compaction methods before such methods can be introduced into the spacecraft hardware [16, 17, 18].

Universal data management systems are becoming essential because of the large number of sensors, storage systems, on-board computers, intercom systems, local radio links, guidance and control units, and redundant communication links. Many of these systems use identical electronic units only during a fraction of the mission's duration. Evidently, common unit usage by several systems could save much equipment. Part of this savings can be invested in redundant designs which increase the over-all reliability. The so-called signal conditioning systems in telemetry are the precursors to such universal data management systems, and their development goes in the direction of general purpose on-board data handling systems [19].

Other subsystems require special space experimentation before advanced designs may be incorporated into future spacecraft. They include stabilization and control systems [20], advanced pyrotechnics [21] (which could avoid contamination of optical surfaces), and guidance subsystems [22]. Life support systems will be discussed separately.

1.3 Man's Adaptation to Space.

In this field of space experimentation, no previous experience was available prior to the first manned space flights. Simulation of space environment on earth has severe limitations, and only man's performance in space can ultimately gain space-life knowledge.

Advanced life support systems are essential for long missions (up to two years). Considerable experience is available from the present manned space programs [23]. The first phase of new development has to consider missions up to 45 days with resupplying the same equipment in space to extend the missions to 135 days. Special bioinstrumentation will be needed for the increased number of men who will be served simultaneously by these advanced life support systems. All measurements need to be tagged to identify the individual astronaut and his responses. This requires new developments in signal conditioning systems and a special internal data distribution system, as the astronauts will be mobile. It may no longer be desirable to transmit all biological monitoring functions to the ground — but, instead, to a biomonitor within the spacecraft. The problem will be complicated when life support systems for larger lunar or planetary communities come under design review. The design of closed-cycle systems for the regeneration of air, water — and, ultimately, food — will bring new payload integration problems [24].

Extra vehicular activities [8] will require a large number of novel tools and instruments, many with electronic or electrical interfaces to other systems. Primarily, the so-called extra-vehicular engineering activities (EVEA) will call for special experimental subsystems (zero-g tools, artificial-g devices, floating tool boxes, etc.) and extended closed-circuit TV systems to observe working astronauts and assist them from inside the spacecraft. Space suits have undergone comprehensive development [25]. Personal radio intercommunication devices have to be integrated into the suit and cabin environment. Their range has to be extended for lunar surface operations. The eleven circles in the EVA line in Figure 1 indicate the complexity of integration effort in this area.

Space medicine and behavior analysis are the oldest areas of space experimentation for manned flight [26, 27]. Fortunately, no really prohibitive aspects of the space environment have yet been discovered. However, there is still a long way to go from a few weeks in earth orbit to lunar and planetary landing, and several years in space. While it seems that the basic instrumentation in this area has passed the first development phase, one can safely predict that many engineering refinements lie ahead. Microminiaturization, digital transducers with memory, increased sensitivity, and simultaneous monitoring of large populations will be some features for further development in this area. Each of these characteristics will affect the payload integration. Notice merely the rfi (radio frequency interference) problem when twelve completely wired astronauts move about in a small space station with radio data intercom, radio voice intercom, and highly sensitive, or high powered experimental equipment, operating in all conceivable spectral ranges. In addition to these engineering refinements, it will be necessary to introduce special radiation warning devices and prepare radiation protection measures. Such prospects may turn into a nightmare for payload integrators.

1.4 Space Environment Exploration

Much has been learned in the first decade of space exploration [28]; but more data, over longer observation periods, are required to make reliable environmental effects predictions. This, in turn, is necessary to design equipment correctly and schedule man's activities in line with his abilities in space environment.

The biosciences extend beyond the medical and psychological problems handled by space medicine (as discussed above) and concentrate on fundamental problems (e.g., What forms of life can use the space environment, including lunar and planetary surfaces, as its natural habitat?) [29, 30]. Special life-detection systems emerge as complex analytical instrumentation, either for unmanned (automatic) operation or for manned analysis in space [31]. Space experimentation with microorganisms, plants, and animals is necessary to explore the bioenvironment in space. Special biosatellites will be flown by NASA in 1966 and later perform one part of this experimentation [32, 33]. Other experiments will be performed in the AAP series of experiments [12].

Bioscience is also concerned with the unintentional transplanting of earth life (microorganisms) to other celestial bodies. Sterilization requirements will have to be updated in line with the results of space bioscience [34, 35].

The payload integration for bioexperiments presents its own problems; they are different from the problems of nonliving experiments and bioinstrumentation for manned flights. Specially designed life-support systems, environmental conditioning systems, bio-medical monitoring systems, and waste management systems are needed. Interference analysis has to consider the influence of strong electric, magnetic, radio, and nuclear radiation fields which may originate in equipment aboard the spacecraft. Another important payload integration task is contamination management, primarily when men and animals are simultaneously aboard [8].

Zero-g physics has been established as a special scientific/technical subarea. Space experiments in zero-g physics are not very difficult, and their results may be of fundamental importance for solid state and fluid physics. It may be one of the first scientific areas where space can be used as a perfect laboratory facility [36, 37]. Other areas, such as cryogenics, high vacuum physics, etc., will follow in using the natural space environment as a workshop for scientific experiments. The instrumentation for zero-g physics includes small centrifuges to produce any amount of controlled g within the zero-g environment. Improved artificial gravitation devices with more homogeneous field distribution are required. A large number of additional laboratory facilities have to be incorporated into a zero-g space laboratory; and, the integration of all these devices, their storage, operation, and readout, presents a formidable task.

Environmental physics is the largest field of space environmental exploration. It involves radiations, electromagnetic and corpuscular, earth magnetism and celestial magnetism, micrometeorites, and the environmental physics of the moon and the planets [38]. This area overlaps with many subareas of space science investigations and solar system exploration. However, only the observed phenomena are closely related. The motivation for the scientific/technical experimentation is considerably different in the area of environmental physics, in space science and for solar system exploration. Also, different are the instruments and, accordingly, the integration problems.

1.5 Space Science Investigations

These investigations are concerned with fundamental scientific observations, correlation of experimental results and theoretical hypotheses, and applications of such results to further research in related areas.

Astronomy and astrophysics are, by definition, the sciences which are most concerned with space. The earth's atmosphere is impeding the observation of the celestial sphere from the earth's surface, and space flight offers the unique opportunity to penetrate this screen. Special orbiting astronomical observatories (OAO) are close to operational status [39, 40], and will carry the most sophisticated instrumentation ever put into orbit [41]. Other unmanned earth satellites and space probes carried instrumentation for astrophysical and solar-physical studies [41]. Manned astronomical laboratories are planned for the AAP missions.

The extreme precision required for astronomy observations is the guiding factor for payload integration in this subarea [40]. Also, the interface between instruments and the thermal subsystem is of major concern. These precision telescopes require equal temperature distribution over the large surfaces of optical elements (mirrors) to retain the original perfect alignment. Vibrations during launch may severely affect the optical instruments, and automatic or manual realignment in space may be unavoidable. Manned optical laboratories may face problems of instabilities due to personnel movements, so specially designed stabilization systems may be required. Contamination of optical surfaces by debris (plume gases) of rockets and thrusters must be watched. This is only a small selection of typical integration problems.

Atmospheric sciences have, presently, the most active interplay with space experimentation. Space flight technology needs many data about the atmosphere and its composition. The atmospheric sciences, in turn, benefit from observations from space or observations in space. Numerous unmanned satellites and rockets carried a large variety of instruments into space. The most sophisticated spacecraft for atmospheric research, today, is an orbiting observatory — the orbiting geophysical observatory (OGO, POGO, etc.) [42]. The atmosphere, in the widest sense, reaches thousands of kilometers out into space and includes zones at different heights above the earth. Names like stratosphere, thermosphere, ionosphere, magnetosphere and exosphere are not necessarily mutually exclusive [43]. They designate atmospheric zones according to different criteria, such as temperature or ionization. Space experimentation finds application in all these zones. Of particular importance, however, are special spacecraft or missions for ionospheric research [44, 45] or for investigation of the radiation belts [46, 47]. A special study initiated by NASA's Office of Space Science and Applications (OSSA) is underway to define the future program of space experimentation in atmospheric sciences and technology [8].

Earth Science studies depend on geodetical [48], geographical [49], gravitational [50], geomagnetical [51] and oceanographic [52] observations, and can be performed best from space. Projects like TRANSIT and GEOS carry experiments primarily in this STA. The integration efforts have to concentrate on the accommodation of synoptic instruments of unprecedented precision. Every effort is made to retain this precision through the launch phase and under hostile space environment. Nevertheless, realignment in space by man- or ground-controlled actuators (in critical places on optical surfaces) may be unavoidable [53] Other important integration areas are the signal-conditioning and signal-processing subsystems which have to handle the extremely large information flow resulting from synoptical sensors. Particular observation consoles are necessary to offer manned observers some quick-look facility and enable selection of those regions where detailed observations may be desired. Pointing systems require at least the same precision as astronomical observations, but the image-forming capability of synoptic sensors imposes a still higher demand on stabilization devices. Further development efforts are indicated.

1.6 Solar Systems Exploration

Unmanned space probes are exploring the moon and the nearby planets. Many special instruments had to be developed for such projects as Pioneer [54], Ranger [55], and Mariner [56, 57]. Payload integration problems of first magnitude had to be solved before these projects could succeed [57a].

Manned lunar exploration will multiply these problems [58]; the goal is the scientific exploration of the moon. Many observations from earth gave scientists fairly conclusive evidence of the moon's motion in space [59], its topography [60], and of some of its surface characteristics [61]. Many problems remain to be solved by direct exploration [62] with unmanned spacecraft [63] and with manned lunar missions [64], primarily through extended surface exploration after landing [65].

The instrumentation for lunar exploration has been extensively studied [66]; and a number of special, highly complex, synoptic instruments [67] and analysis instruments are under development. The payload integrator has to meet new, still partly unknown, environmental conditions. His systems engineering effort now has to reach far beyond the confines of a spacecraft. The exploration system is now deployed over large parts of the surface and "vacuum space" of an unknown celestial object, and involves a large number of men, shelters and surface vehicles. New extended and complex subsystems, such as the lunar surface communications system, have to be integrated; and their characteristics and operation have to defeat a medium which, for example, the sound of the human voice cannot propagate.

The payload for planetary exploration may follow the development of payloads for lunar exploration [55a] except that the missions' inflight duration will increase to years, and the environmental surface conditions will be different from planet to planet. Unmanned fly-by missions to Venus [56] and Mars [57] have already been established, and instrumentation on their flights performed as expected. It is necessary to build on this experience when attempting planetary orbiting and planetary landing with unmanned [69] and, finally, with manned spacecraft [70, 71] .

Figure 1 shows that the major areas of payload integration are communications transmitters with associated data handling units [72] , the guidance and navigation system [73] , and analysis instruments with their associated instrument consoles. Of all these problem areas, the communications system is the one requiring revolutionary new approaches to achieve the goal of real-time picture transmission over planetary distances. There is hope that optical deep-space communications systems may achieve this feat [74] , but the technological and operational problems to be solved are tremendous [11] .

Solar exploration presents a payload problem different from lunar or planetary exploration. There can be no landing; even a close approach is impossible. The scientific exploration is continuously taking place by conducting observations about solar radiation, solar winds, and interplanetary plasma aboard practically every spacecraft on a trajectory above the lowest earth orbits. Special orbiting solar observatories have been successfully launched [41, 75] , and these projects are continuing [76] . Spacecraft in the Pioneer and Explorer series contributed to the increasing knowledge about the sun and its radiations. Special "close-in" solar probes are planned for the future [77] , and the payload integrator has to answer the questions:

a) What maximum distance from the sun do experiments in a solar probe offer enough improvements over similar experiments carried aboard earth satellites to justify the additional technical difficulties of approaching the sun?
b) How can one solve the thermal problems expected at the desired closest approach?
c) What assumptions can be made about radiation damage, radio wave propagation, and solar winds at such close proximity to the sun?

1.7 Space Utilization

Most discoveries have the potential of becoming significant advancements for the human race; this may also be the case with the experience and discoveries resulting from space exploration. For instance, some results in weather observations and communications are already available. The payload integrator has to consider utility for the population on earth as the ultimate goal of all space experimentation.

The following five subareas of space experimentation are those which require longer periods of experimentation with developmental hardware and, therefore, will be important for experiment/payload integration.

Earth resources statistics is a new space utilization subarea of great interest in connection with the AAP [12] . The Saturn boosters and the Apollo spacecraft offer the possibility of launching large manned payloads into any desired orbit around the earth. Polar orbits are naturally the most desirable trajectories for any continuous observation of the earth's surface. With the large payload capability and man's presence, many earth observation tasks become feasible which would not be possible with smaller booster-spacecraft combinations. Earth's increasing population will cause shortages of many resources, such as crops, forests, water supply, wild life, and ocean resources. It will become essential to avoid waste and losses, even in areas which are not yet completely cultivated. Regular and all-inclusive surveys from orbit will enable international economical planners or individual nations the most economical development of all earth resources. NASA's Office of Space Science and Applications (OSSA) will conduct special studies in cooperation with the Department of Agriculture and other government agencies to define the nature of such earth resources statistics flights [8] . The instrumentation of such earth survey flights will utilize any applicable method of synoptic and analytic instrumentation. Much higher precision equipment is needed in weather satellites. A large variety of parameters, in all spectral ranges, needs to be analyzed. The payload integrator has to find the right balance between automatic recording and man's ability to select intelligently the most interesting field of view (FOV) plus efficient methods of sensing the appropriate physical magnitudes.

Weather and flood observations need further improvements. The experience gained with the first operational weather satellites [79, 80] is an excellent basis for improving unmanned and manned systems. In this subarea, more than in any other, man may act as a supervisor of an unmanned system. Space ferries will be available to bring man for short servicing periods to unmanned weather satellites. The

AAP program will test instruments and systems for this purpose.

The payload integration of such manned/unmanned hybrid missions presents a number of unique problems. Accessibility of equipment has to be provided for manned repairs. Control consoles and test equipment must be available in the unmanned spacecraft module. Voice communication links are desirable, yet all the command and telemetry links have to operate in the same way as unmanned operational systems.

Communications and navigation satellites will also benefit from a similar operation with manned supervisory capability. In the case of synchronous communications satellites, one may even think in terms of a switchboard in space with a complete computer-directed switching center aboard and many highly directional microwave or optical beams — each oriented toward a specific ground station. Such concepts appear less attractive without manned service and maintenance capability available at regular intervals.

Space experimentation, with prototype hardware for such advanced ideas in weather, communications, and navigation applications, will be tested by special applications technology satellites (ATS) [81] and on certain flights of the AAP [12] . Prior to these projects an unmanned global communications satellites network might be in operation, which will, at the beginning, have a larger capacity than is presently required [82].

Special integration problems in this area are: a) the need for increasingly large antenna structures, b) the heavy power requirement for strong transmitters and c) the necessity of working without interruption with several ground stations. To promote this subarea of space utilization [8] NASA's Office of Space Science and Applications is directing a special study to define in detail those space experiments which could be incorporated into some of the planned space missions within the next five years.

Space mining is a possibility in the more distant future. Presently, it sounds like science fiction, yet serious scientists have amassed statistical facts to present a "case for mining the moon" [83] as a first step toward space mining. It may not be too early to have a look at the integration problems on moon-mining missions. Major difficulties may be power-supply problems and the assembly and operation of special machine tools and mining machinery on the moon due to lack of atmosphere. However, the fact that the moon has a much smaller gravitational constant may be a good advantage. Other critical areas of systems integration will be the: a) life-support systems for large work forces, b) need for numerous airlocks in all shelters, c) necessity to provide for thermal control systems everywhere, d) need to invent, develop, and test many novel instruments used to detect and analyze unknown materials which may be produced by the mining operations.

Space environmental utilization may develop earlier than space mining. It is evident that space offers environmental conditions which cannot be produced on earth in sufficient quantity and extent, even at the price of billions of dollars. A recent publication [84] mentions the following twelve specific vacuum and cryogenic projects: Materials research, thin-film technology, metallurgy research, welding research, coating applications, spectroscopic studies, vacuum distillation, electron-tube research, superconductivity, conduction at low temperature, cryobiology and microminiaturization. These projects (many more could be conceived) could be done more economically in a moon laboratory, with its natural vacuum, than on earth, where perfect vacuum in large enclosures is nearly impossible. Beyond such laboratory activities lie possibilities for efficient manufacturing by utilizing the special lunar environment [85] .

The lunar systems integrator faces problems of instrumentation which reach beyond space mining. The complete lunar laboratory equipment has to be designed for unique environment. Special radiation protection will be required for many electronic devices. Little is known about seismic conditions on the lunar surface, and special antivibration devices may be needed. Residual gases could impair the ideal vacuum, so that pumping or outgassing may still be required for very special experiments. The normal temperature measurement through convective circulation of air is not feasible. This is only a small selection of the yet unexplored problem areas for lunar system integration.

PART 2. SPACECRAFT SUBSYSTEMS

Space experimentation in the field of the scientific technological areas (STA), discussed in Part I, requires many subsystems aboard a spacecraft. These are plotted in Figure 1 as vertical columns. The various symbols at the intersections of the subsystems columns, with the STA rows, indicate the character of the respective interface between an STA subarea and a subclass of subsystems.

2.1 Instrumentation

This is the most essential hardware in any experimentation. In space experimentation, in particular, most instruments are input devices to other electronic systems and, in the widest sense of the word, may, therefore, be called sensors. Exceptions are the last two subclasses, which incorporate chemical, physical and biological instruments with direct reading capabilities or for manipulating purposes, so that no electronic connections are required.

The subclass of synoptic instruments includes large optical telescopes, telecameras for photographic or kinematographic recording, television cameras, plus a host of scanning instruments from radiometers, in all frequency ranges, to synoptic radar sets and scanning optical beacons.

Analysis instruments are fairly complex subsystems by themselves with amplifiers, logical devices, sweep generators and other special electronics circuitry. The payload integrator will do well to check the commonality of such auxiliary units, when several analysis instruments are needed within the same payload. Savings in hardware will result if duplication is avoided; or, alternately, redundancy may be arranged intentionally to increase the reliability. Examples of analysis instruments are spectrographs, mass spectrometers, power spectrum analyzers—also, biochemical analyzers for life detection or metallurgical analysis instruments for space mining.

Monitoring instruments are, in general, small devices with some programmed function, such as a maximum-minimum thermometer or a radiation monitor with adjustable threshold value. This subclass of instruments will actuate some electronic device or functional unit, whenever the monitored magnitude coincides with a preprogrammed value or function. The payload integrator has the responsibility of: a) incorporating these instruments into the total system, b) investigating all interference possibilities, c) providing fail-safe operation and d) arranging for check procedures for the monitoring devices themselves. Their actions will need priority over many other automatic operations, and sequences have to be programmed accordingly. New developments in this subclass may be needed only for space mining; but some STAs, primarily bioexperimentation, require a large number of such monitoring devices, and their integration may call for complex planning effort.

Transducers are well-known devices in the instrumentation of experimental aircraft and are widely used in manned spacecraft. Basically, one may define a transducer as a device which provides an electrical magnitude in proportion with a given physical magnitude. Thermocouples, piezo-electric accelerometers, resistance thermometers, resistance strain gage balance, induction transducers, or potentiometer accelerometers are just a few examples [86].

Special Bioinstrumentation is needed whenever man or animals go on space flights. Rather complex instrumentation systems have been developed and are in operation. Simplification, microminiaturization, and improved precision will be the goals of additional development efforts. New developments will only be required in connection with advanced life-support systems and space mining. The assembly of larger numbers of astronauts (or space workers) within one life-support area (space station or lunar shelter) will present new integration problems involving bioinstrumentation. Space mining would surely be an STA requiring a larger population of spacemen.

In general laboratory instrumentation one has to consult the special experiment definitions for a survey of all the instruments and apparatus which scientists desire in space laboratories. In the near future, the payload integrator will be concerned with all sorts of zero-g equipment such as small centrifuges, bubble chambers, and apparatus for liquid material investigations. Special thermostats and cryostats, small ovens, standard electrical instruments, and others, will be added. The payload integrator has to take care that all these instruments and auxiliary apparatus will be adequately secured during launch, in zero-g environment and for reentry. The experience with early manned space laboratories will ultimately be used for the design of space utilization laboratories. It is conceivable that completely new instruments may become available for this ultimate space experimentation goal.

Special experimental subsystems incorporate everything else that may not fit the description of the above classes. One example is equipment and apparatus for extravehicular engineering activities.

2. 2 Data Management

The amount of information supplied by all the instruments in these many areas of space experimentation will increase as the experimental methods become more sophisticated. In some STAs (e. g., planetary exploration), the information flow is extremely high during a short time interval (e. g., during fly-by) - and, practically zero during other times. Such uneven loads (also, complex inputs, distorted inputs, etc.) are cases to be handled by advanced data management systems. Four distinctly different functions are normally performed by a data management subsystem and are mentioned below.

Signal conditioning is at the input side where the information arrives from instruments (sensors). It involves the: a) amplification of weak signals, b) combination of signals from many sensors (multiplexing), c) conversion of signals into waveforms or formats which are more suitable for the remaining data management operations and d) operations to discriminate essential information from nonessential. The latter operation is called redundancy reduction, signal compression, or information compaction. It may be performed at various levels; e. g., directly at the sensor, in the signal conditioning equipment, or in the data processing part. There are many tradeoffs between these possibilities, and the payload integrator has to consider several of them in his optimization effort. It can be safely predicted that several of the STAs will not be able to perform efficient space experimentation without some form of information compaction.

Data storage is the usual way to handle uneven information loads. Data storage systems have been developed for many space missions in the past [87]. Improvements are needed and may be expected in the direction of larger storage capacity, smaller size and weight for the same capacity, random access capability and faster access time.

Data processing is used in spacecraft for guidance and navigation [20]. It is an analog operation where immediate reaction is needed (such as in controls systems) and a digital operation where extreme precision is required (such as in orbital calculations and as a navigational tool) [22]. Ultimately, most of the data processing will be digital, due to higher flexibility and accuracy of the mode and better compatibility with storage and communications systems. Spaceborne computers are already small miracles of technology and will undergo further spectacular development. They will truly become the brain and the heart of future universal data management systems.

Signal processing, distinct from data processing, is an operation on noisy, distorted, (i. e., contaminated) signals. It may be applied as part of a signal conditioning operation, when the task is the noise-stripping of input information. This is the case for radar return signals, and output of television camera tubes. Signal processing may also be applied as part of a communications system to separate the received weak signals from the simultaneously received noise. Also, it may be helpful as an analytical tool for identifying and classifying signals picked up by a variety of sensors for space science tasks. Advanced booster development, practicularly in the area of recoverable boosters or reentry craft, will require improved reentry communications and telemetry links. Signal processing is one of the proposed methods to bring improvement to this crucial area of space exploration. Other critical integration demands for signal processing subsystems are indicated in the area of earth sciences and earth resource statistics. The analytical capabilities of signal processing systems ("finger printing") will be required in these STAs.

2. 3 Communications Subsystems

For many decades, space experimentation will depend on a real time link to the ground. However, experimentation during manned flight or on the lunar surface will, to an increasing degree, become self-sufficient; and the communications link to the ground will transmit summary results only. The data management subsystem, discussed above, will be responsible for both the handling of local data and the derivation and selection of essential data to be transmitted to the ground station on earth. Notice, however, that some of the STAs (such as optical communications or the communications subarea under space utilization) make communications the subject of space experimentation. Special interface situations between the communications experiment and the operational communications subsystem emerge in this case.

Antennas are the gateway from the spacecraft to the communications medium. A good communications link is dependent on antennas, and every effort will be made to improve them through special space experimentation. Extravehicular engineering activity will be applied to erect large experimental antenna structures in space. Spacecraft antennas present very peculiar integration problems: a) They have to be protected during launch and reentry, b) they have to be unfurled or inflated and expanded in space, c) they may interfere with the FOV (field of view) of optical instruments, or with the operation of solar paddles and booms for special instruments, and d) they may present real hazards during extravehicular activities (EVA) or during rendezvous and docking maneuvers.

Transmitters and their radiated power determine the range of communications links. New developments are needed for planetary distances if picture transmission in real time shall be achieved. Another development problem prevails concerning more efficient, smaller transmitters for rockets and balloons, which are able to handle wider bandwidths than the present designs. Lunar surface exploration has requirements for many small relay transmitters as part of a lunar data-gathering network.

Spacecraft receivers are adequately designed for most applications where they receive transmissions from earth. Receiving earth's radiation as noise into the receiver is unavoidable; therefore, an ultimate low noise design is not required. The situation will be different for receiving in space or on lunar surface transmissions from other spacecraft. For these applications, low-noise receiver input devices with cryogenic subsystems will be desirable.

Voice intercommunications equipment is absolutely essential for manned flight. The larger number of crew members in manned stations and on lunar surface expeditions calls for new designs with random access capabilities, so that any crew member can address selectively any other crew member or any group.

Internal data distribution systems within space stations, or for all lunar surface units, will be desirable to handle, simultaneously, the information of many experiments, and will permit vital monitoring instruments to break into all other communications when warning messages are necessary. Data buses (data collection lines) will be needed with access to many places. Such systems will be closely linked to any future universal data management system.

Closed circuit TV systems establish the link between inaccessible instruments and corresponding control and display consoles in life supported enclosures. They are a major headache for payload integrators. Ideally, there would be a universal TV intercom system with a single universal console. Unfortunately, the available standard camera designs of closed circuit TV systems are not compatible with many requirements of space experiments. There are needs of UV, X-ray, IR and other image converters. Some experiments are better served by storage-type image converters while others require absolutely nonpersistent, short recovery imaging devices. Also, some need high resolution pickup tubes while others require integrating large area light conversion units. The result of this situation is the need for an individual design for each flight, based on a common distribution and display system.

Astro surface communications (i.e., communications on the surface of celestial bodies) is a new branch of communications technology which may emerge from tactical army communications or from commercial mobile ground communications systems. Unfortunately, these technologies are in a rather backward state of development in an age of signal-processing radars and hi-fi stereo music transmissions. There is a need for new breakthroughs which may possibly emerge from the still embryonic efforts toward RADA (random access discrete address) systems. Microminiaturizations, electronic steerable antennas, solid-state microwave devices, and signal processing techniques must be further improved to give future spacemen the personal communications means which so far exist only in science fiction. ESP (extra sensory perception) may ultimately lead to some bionics communications systems, but few will volunteer to predict such possibilities for the 20th century.

2.4 Control and Display Subsystems

Unmanned spacecraft need merely a patchboard to provide flexibility in adding or modifying experiments late in the test and checkout phase. Manned spacecraft require a variety of operational controls to fly the spacecraft and a greater number of indicators to supervise the operation of the spacecraft [88, 5, 6]. Manned space experimentation has the additional requirement for controls and displays to operate experiments from within the pressurized modules of the spacecraft and a new special manned space laboratory design should take these requirements into consideration. The Apollo Applications Program has to use the existing Apollo modules. Pressurized areas are only in the command module and in the LEM ascend stage. The addition of control and display devices for space experimentation creates a major integration problem as these Apollo modules are crowded with essential equipment. For earth orbital missions, it is possible to remove some of the equipment needed only in lunar-landing missions and replace it with experimentation units.

Monitoring consoles comprise the smallest variety of control and display devices. Primarily they contain signal lights and switches to indicate normal operation of experiments and switch them on and off. A certain flexibility can be added by providing a few universal electrical instruments to permit quantitative monitoring of vital experimental magnitudes. A patchboard, or a switching matrix with punched card type of programming, may be used to adjust the display to the requirements of different experiments.

Control consoles are the medium-size devices which permit orientation control of directional experiments and adjustment (possibly, calibration) of important parameters of these experiments.

Observation consoles belong to the largest class of display systems — those which can operate complex experiments completely by telecontrol, and permit the astronaut-scientist to extract significant results directly at his desk. They contain pictorial displays for synoptic experiments, and operate with large electronic systems for signal and data processing. Interfacing directly with the universal data management and communications systems, they relay summary results to the ground station. Closed-circuit-TV-picture tubes are incorporated into observation consoles.

Integration of these devices is a complex systems-engineering and human-factor problem. Each class of experimentation has different demands. Also, a critical tradeoff exists between the direct control of experiments in unpressurized environment and the operation by telecontrol from complex consoles within the pressurized modules. The number of sorties (exit from pressurized modules) per flight is limited and depends on the availability of airlocks. The astronauts' activities are somewhat restricted with space suits. For example, the direct observation through the ocular of a telescope or microscope is impractical.

2.5 Astronautical Subsystems

These are the spacecraft's subsystems which have to secure the desired flight conditions, and are closely associated with many phases of space experimentation.

Navigation and guidance subsystems enable the experimenter to derive the positional data and distance from other stations participating in an experiment — thereby permitting him to orient directional experiments [22]. Developmental models of advanced navigation and guidance systems will be the subject of space experimentation. Operations for rendezvous and docking, lunar-surface and planetary-landing need further experimentation with special devices of this class [73]. The payload integrators' problems are in the areas of test and calibration methods, astronauts' training, and interference management.

Attitude control and stabilization systems are the key to many astronomical-, astrophysical-, and earth-oriented synoptic experiments. Pointing accuracies within 0.1 second of arc have to be imposed to fully utilize today's advanced optical instruments once they operate outside the earth's atmosphere. Complex gimballed suspensions and electronically controlled optical coarse and fine correction systems have been designed to achieve this precision. All these devices have to cooperate with the spacecraft attitude-control system [20]. The result is an unusually complex control system of high order which requires simulation on the ground, detailed analysis of all conceivable perturbations, and a very delicate study of man's performance within the control loop. The hybrid operation (manned-unmanned-manned), which may be foreseen for many missions, is a cause for additional complications.

Secondary propulsion involves all onboard propulsion of a spacecraft, but excludes propulsion units of launch vehicles (boosters) [15, 89]. In Part 1 we mentioned this class of subsystems as a STA subarea, as many new developments are in sight. Primarily, the payload integrator is interested in the influence of the presently available units on various experiments. Interference of exhaust gases and debris with optical or radiation experiments has to be considered. Another problem is mechanical transients and vibrations after thruster operation.

2.6 Structural Subsystems

One may assume that structural subsystems have little in common with space experimentation. However, payload integrators realize that the mass management of a total spacecraft may severely affect the positioning of instruments. Magnetic balance is another important topic when magnetically sensitive instruments are aboard. Future space experimentation will use instruments of large mass (e.g., 40-inch telescopes), and many special structures — such as booms — are needed for other experiments. A basic knowledge of structural concepts [90] and materials [91] is essential for payload/experiment integrators, and will help them recognize critical interface problems.

Airlock and windows are structural units of utmost importance for space experimentation [8]. The number, size, and construction of airlocks determine the character of all experiments with extravehicular activity, and, also, the size of objects which may be retrieved for return to earth. Windows include structural elements with transparency for other than optical radiation. Radomes for radio antennas; small openings for X-ray penetration; and, gasproof bushings or grommets for carrying lines, cables or waveguides through the structure may be included. These elements are the visible interface between experimentation and structure. A less visible interface is in the radiation area, where structure acts as a screen for some radiations, and is transparent for others. The interior environment affects experiments performed within the confines of a structure. In turn, the transparency, or reflectivity, of the structure for certain radiations and other side effects, (originating from experimental units) are important for interference analysis and contamination management. The structural elements (in particular, airlocks and windows) are also essential elements of the acoustical and vibrational environment. This is a factor that cannot be neglected when integrating certain experiments and instruments.

Expandable structures range from unfurlable booms and antenna rods to huge inflatable radiators or shelters. Most of these devices require pyrotechnics for their release which is of major concern to the payload integrator [21]. Solar paddles are possibly the oldest type of expandable structure, and similar devices have been used as a carrier of micrometeorite sensors [92]. As the number of expandable structures increases, the integration job becomes more difficult. Mutual interference is one problem; also, reliability, drives, control devices, and interconnections must be considered. Some of these structures are not retractable and pose a sequencing problem for experiments which require expanded structure against those which may be impeded by it.

Secondary structures are those which may be moved continuously relative to the spacecraft, or those which can be completely separated from it (ejected). The first group of secondary structures is best represented by the "sail" and "wheel" of the orbiting solar observatory [93]. These are two separate structures of the spacecraft which can be continuously rotated in space with respect to each other. The shaft of the sail rests in a "space-proof" bearing fixed in the center of the "wheel." Similar arrangements, of much larger scale, will be used in rotating space stations. The electrical connections between the rotating structures warrant the full attention of the payload integrator. The second group of secondary structures include small maneuverable satellites (SMS) which can be launched from the spacecraft, performing a variety of chores for space experimentation. They will be controlled from the spacecraft by wire or radio. Closely related to astronauts maneuvering units (AMU), SMS are designed for unmanned use, as a kind of space robot. One possible application is assistance in the erection of large antenna structures for radio astronomy in lower frequency ranges. These SMS may be the forerunners of space taxis, cargo transfer modules, or space ferries which will be operated by men and needed for the operation of large space stations [8]. Space experimenters will become familiar with these devices when performing development experiments. Later, these devices will be essential tools in using extended experimental structures or when attempting to sample the space environment over an extended sector of space. Their inclusion into a space system presents new integration problems such as checkout, launch and control. They should be retrievable and will have to be docked and maintained. Experiments will have instruments in these secondary structures which have to cooperate in real time with other experiments in the primary structure.

Thermal subsystems are not necessarily a part of the structure. They are included because the thermal balance of spacecraft depends, to a large extent, on passive thermal devices which form part of the structure [94]. The interface between space experimentation and thermal subsystems has many other facets. Active thermal devices (e.g., thermostats and cryostats) are required to keep certain experimental units at constant temperature. Thermal control is needed when experiments are performed where temperature is a controlled variable.

Pointing subsystems were already mentioned (Astronautical Systems, Part 2, 2.5) as stabilization subsystems. The term pointing systems is wider than the term stabilization subsystem. The pointing system includes the gimballed suspension of an instrument or the provision of a more universal gimballed platform. As such, it forms clearly a part of the structures. However, it requires a sophisticated electronic control system to achieve the precision which space experimentation requires. The selection and integration of a suitable pointing system is a major problem for any payload with directional precision instruments [11, 40].

2.7 Support Subsystems

Space experimentation, like many other space activities, depends on a number of auxiliary functions which have to be performed to keep the experiment going. There is, naturally, a grey interface area for deciding where the experimenter's (principal investigator) responsibility ends and spacecraft designer's responsibility begins. The grey area is widest in the class of support subsystems. The experiment/payload integrator has a big responsibility in placing the position of this interface correctly. The following comments will clarify this point.

Power supply subsystems are needed for most instruments. At present, spacecraft — like earlier aircraft — use a 28-volt busbar dc power distribution system [14]. There are, however, many subsystems which are served better by an ac power source. The designer has the choice either to assign individual inverters to such systems or to provide an additional bus with ac supply (115v). Ultimately, with the changeover to fuel cells or atomic reactor auxiliary power units (APU) [13], a common ac distribution system may become the rule. Notice however, that there are compelling reasons for a dc distribution system, so that the optimum solution may very well be a dual distribution system of dc and ac, with one acting as backup for the other, as far as vital subsystems are concerned. For experimentation hardware this would be an ideal solution, and integrators would definitely welcome it. Going beyond this possibility, experiment integrators are seriously considering a standard frequency distribution system; and, for certain payloads (for a limited laboratory area), a high voltage distribution system (about 2kv).

Instrument support systems can assume many forms such as small motors or actuators to perform some mechanical chores, or large electronic signal processing or data processing systems to perform analytical operations. Some of the candidates for instrument support equipment are: thermal stabilization systems, controlled-g systems, small life-support systems for animals, pumping systems for creating controlled gas or fluid pressure, illuminating devices, antivibration systems, and small stabilized support systems. This large variety poses a serious problem for experiment integration. Each new device has to be carefully analyzed for its compatibility with the overall system. Simple gadgets which perform flawlessly in earth laboratories may cause trouble in space, contaminating the recirculated atmosphere, being sensitive to radiations, or damaged under the heavy g stress during launch.

Electronic support systems are those electronic devices which may be used simultaneously by many instruments, but still are not general enough to qualify as separate subsystems. High-voltage or standard-frequency supply systems (when limited to a special location) may be considered better members of this class than the power supply class. Timing systems (including electric clocks for universal time [22]), special synchronization subsystems, local data concentrators, subcommutators, dc amplifiers, operational amplifiers, and many others, may fall into this class once they serve more than one instrument (experiment). Thus, they become the responsibility of the experiment/payload integrator.

Life-support systems are standard hardware in manned spacecraft [23]. Larger crews in space stations will present new problems. Space experimentation (particularly in the biological sciences) imposes many special demands, exceeding the capabilities of regular life-support systems. Nothing, however, is anticipated which would require completely new designs in this area. The integrator has to concentrate on: a) effects in the contamination-management area, b) the sequencing of experiments, and c) the monitoring of proper functioning of all life-support activities, primarily when there are a variety of animals aboard. Disposing of deceased animals is one problem which may be easily overlooked, and a whole mission could be jeopardized if it remains unsolved (death support systems ?).

Extra vehicular engineering activity (EVEA) support systems are emerging from the conceptual phase. Fortunately, man's craftsmanship is based primarily on muscle and brain activity; there are, nevertheless, a number of chores which depend on, or are aided by, gravity. Design of special EVEA tools which operate on a magnetic basis will aid future space mechanics.

2.8 Conclusions

Referring back to Figure 1, we can now understand the magnitude of the experiment/payload integration task. There is hardly any area of science or engineering which is not involved. This fact alone should be of sufficient proof to state that space experimentation will offer valuable fallout in many earth industries not directly connected with the space venture at present. How efficient this fallout will be depends, first of all, on our ability to transfer the technological progress from space-oriented industries to other applications [95].

The paper on payload integration (see footnote, page 1) will show how this difficult task can be organized and how teams of specialists can cooperate to control the multi-dimensional interfaces presented in this paper.

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