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XI.1

PAYLOAD INTEGRATION FOR SPACE EXPERIMENTATION

by

P. C. Green
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INTERNATIONAL BUSINESS MACHINES CORPORATION

Federal Systems Division
Space Systems Center
Huntsville, Alabama
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ABSTRACT

Space experimentation requires an increasingly complex planning and systems engineering effort to meet the demand for highest precision and reliability of all measurements and observations. A companion paper* discusses the interfaces between the scientific/technical areas of space experimentation and the instruments, subsystems and support systems within the spacecraft.

This paper deals with the organization and the procedures which are needed to perform the difficult payload integration process for space experimentation. In the course of this process it is necessary to define the experiments completely, to describe all instruments in terms of engineering specifications, to investigate the commonality of equipment, to group the experiments into mission compatible payloads, to specify acceptable loads on all subsystems and astronauts (when present) and to plan for all contingencies during the flight.

INTRODUCTION

Payload integration for space experimentation is the planning, design, and operational activity necessary to match the demands of the principal investigators and experimenters with the availabilities of the spacecraft, ground facilities, and personnel.

Section 1, Organization of Payload Integration, discusses in general terms the inputs to the integration process, the integration functions, and the outputs of the activity.

Section 2, Experiment Description, details some methods which have been useful in transforming experimental requirements into specifications of impact on supporting equipment and personnel.

Section 3, Commonality Matrix, discusses a technique for the identification of commalities and the associated potential benefits of sharing and standardization.

Section 4, Flight Matrix, highlights an approach to the detection of incompatibilities between experiments and flight parameters and suggests means of capitalizing on flight commonality.

Section 5, Load Matrix, covers methods which have been used to allocate experiment support expendables optimally to satisfy experiment requirements.

Section 6, Experiment/Spacecraft/Ground System Interfaces, treats the sensitivity of experiment support requirements to the location of interfaces between the experiment apparatus and the support equipment.

While the breadth of the subject precludes detailed treatment, this paper is presented with the hope of providing a general familiarity with it.

LIST OF ABBREVIATIONS

AAP	Apollo Applications Program
AMU	Astronaut Maneuvering Unit
EVEA	Extra Vehicular Engineering Activity
EXOTIC	Experiment Operation and Test Integration Concept
FAST	Functional Analysis and Specification Tree
HC	Hardware Concept
IR	Infrared
RFI	Radio Frequency Interference
STA	Scientific/Technical Area
UV	Ultraviolet
VECTOR	Not an acronym; descriptive name for a program.

*R. F. Filipowsky and P. C. Green, "Interface Problems in Space Experimentation (in these proceedings, pp.____).

1. Organization of Payload Integration

Payload integration may be viewed as the optimal accommodation of experiment requirements by space vehicle availabilities. Figure 1 illustrates the general procedures involved. Major inputs to the flight-objective-definition function are provided by governmental sources, working cooperatively with principal investigators, institutions, and industry. These inputs are in terms of available vehicles, flight schedules, candidate experiment schedules, and grouping rationale. In turn, the flight-objective-definition function defines for each flight:

a) Launch vehicle(s),

b) Space vehicle(s),

c) Major experimental objective(s),

d) Preliminary orbit parameters, and

e) Rationale for experiment grouping.

The payload-planning and experiment-selection function receives these data as inputs and develops a payload plan consisting of:

a) Conceptual grouping of experiments resulting from recognition of scientific priorities, inter-vehicle and intra-vehicle trade studies, and experiment requirement commonality.

b) Technical descriptions of the apparatus implicit in the grouping.

c) Mission analyses including final orbit parameters, payload capability, lifetime in orbit, environment in orbit, flight sequence of events, and the launch window.

d) Reliability analyses including critical reliability trade parameters, numerical reliability goals and apportionments, and special reliability problems inherent in selected experiments.

Possible advantageous alterations of the experiments discovered in this process are referred back to the flight-objective-definition function for consideration as amendments to the affected experiments.

Results of the payload-planning and experiment-selection function, in terms of conceptual payload and orbit, are used by the experiment-vehicle-integration function in the performance of: subsystem, crew participation, reliability, data management, and experiment pointing trade studies. Based on results of the trade studies, specifications are generated for the required subsystems (see Figure 1 of Reference 1).

Integration constraints identified in the experiment-vehicle-integration function are referred back to the payload-planning and experiment-selection function for consideration of possible changes in conceptual payload or orbit.

Hardware specifications are converted into definitions or designs by the hardware-definition function, and, subsequently, plans may be developed for: logistics and supply, fabrication and installation, ground systems, test programs, training and simulation, and mission planning.

The most demanding function in Figure 1 is that of experiment/spacecraft integration because it includes the solution of interface problems discussed in Reference 1, and schematically indicated in Figure 1 of that paper. The organization needed to perform the experiment/spacecraft-integration function encompasses both the government contracting agency and industrial hardware contractors. Especially large integration projects may require the assignment of an industrial contractor to perform the experiment/spacecraft-integration task exclusively. Figure 2 shows one possible organization chart for this task. The example STAs, subsystems and missions are selected for consistency with recently published plans for the AAP [2]. For any other programs (primarily for a smaller specialized integration effort), teams of specialists in other appropriate subareas (e.g., systems and missions) should be selected. The principal investigators (top line) submit proposals for experiments to the contracting agency, who — usually with the help of the payload integrator — select experiments, call for their preliminary description on prescribed forms, and arrange them in preliminary flight packages. These flight packages contain descriptions of all experiments which are tentatively scheduled for the same flight. Additionally included are a number of experiments which could be used as alternates.

The organization, shown in Figure 2, receives all the experiment descriptions, either individually or prearranged in flight packages; and, many specialist teams of systems engineers go through a detailed review of the descriptions, evaluating the requirements of all the subsystems (see left side of the chart). The organization receives simultaneously, definitions regarding proposed missions parameters. Teams of mission analysts review these data and derive a mission profile describing the necessary launch vehicle, launch operations, and flight operations. The results of all these reviews are then compared, incompatibilities removed, and tradeoff calculations made to arrive at an economical, completely compatible and feasible, new payload plan for each flight.

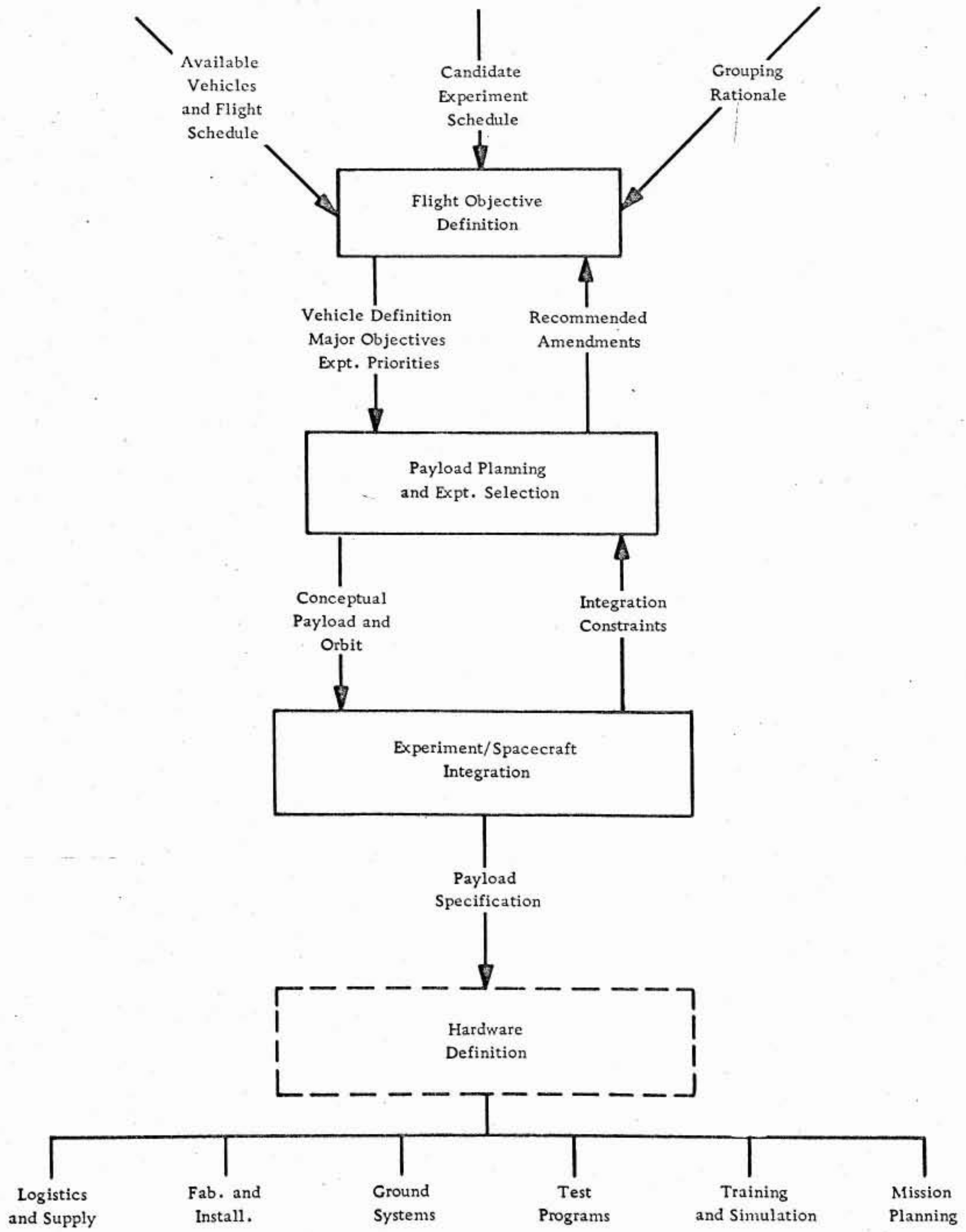


Figure 1. General Payload Integration Functions

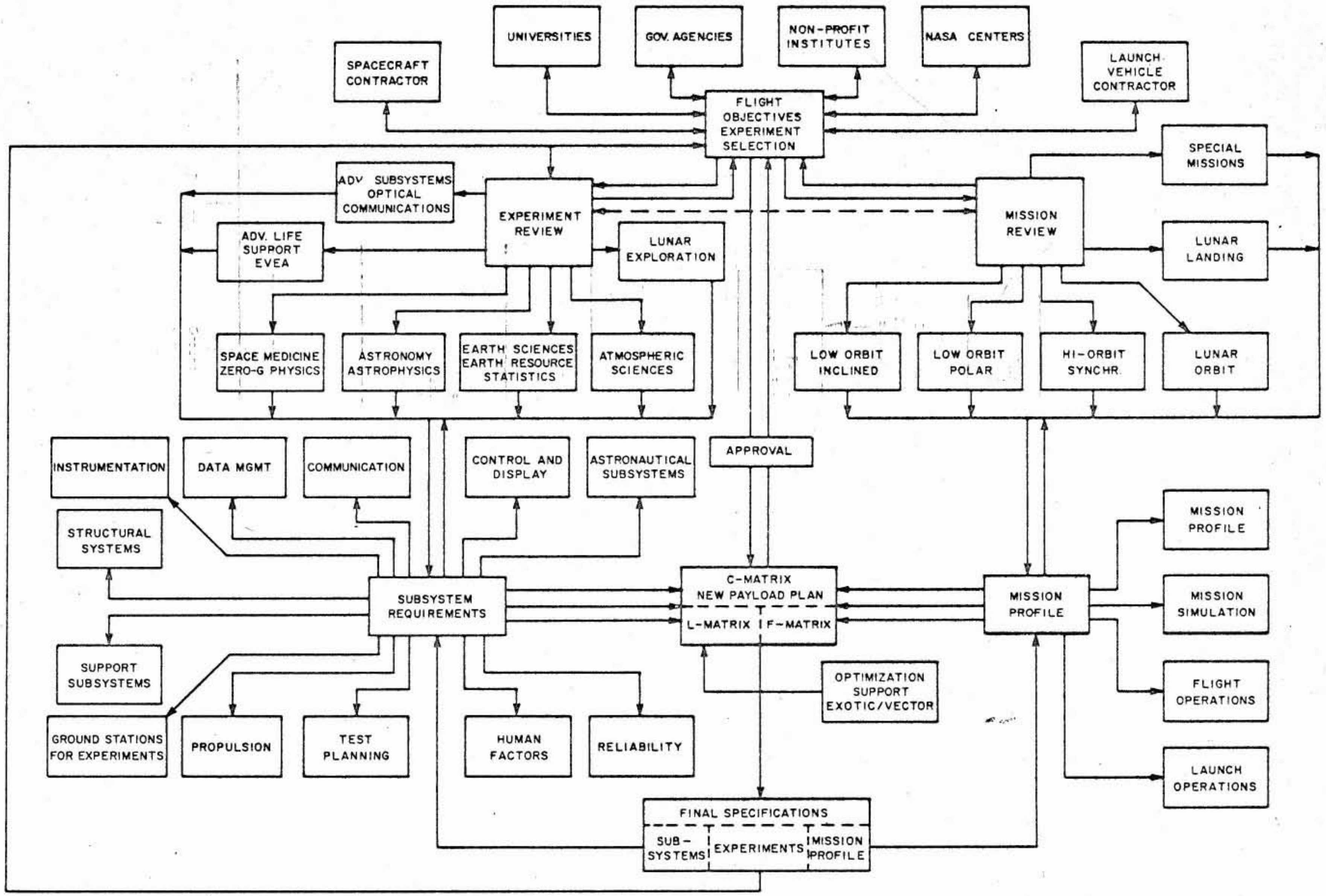


FIGURE 2. ORGANIZATION FOR EXPERIMENT/SPACECRAFT INTEGRATION

During the formation of this plan, it is useful to plot all the available data in three matrices: the C-matrix (compatibility matrix), the F-matrix (flight matrix) and the L-matrix (load matrix). These are discussed in more detail in the following sections. Computer methods facilitate the preparation and manipulation of these matrices when large numbers of variables enter the optimization procedure.

The new payload plan is finally submitted to the engineering teams who will write specifications for experiments and subsystems — clearly defining the interface and the responsibilities for the development, testing, assembly, and check out of all units. Section 2 describes some management control procedures which may be used to facilitate this activity. A critical timing problem exists in developing formal specifications consistent with management control procedures. A large program (such as the AAP) will require an enormous amount of detailed specifications. Also, the very nature of a space experimentation program necessitates flexibility in accommodating new or modified experiments as close as possible to the launch date. If the specification phase is entered too early, the flood of formal change notices becomes burdensome; if entered too late, uncertainties regarding responsibilities, delivery dates, and test requirements will prevail, resulting in confusion. Large programs will have to stagger the payload assignments in conjunction with the flight time table and the complexity of the individual experimental units and their interfaces.

2. Experiment Description

Candidate experiments are identified, ordered, and scheduled by: a) recognizing and ranking man's data requirements for the future, b) extrapolating the state of the art in STAs to determine the projected availability of required apparatus, and c) determining the future practicability of mission profiles needed to attain the required data. The first major milestone of payload integration is reached when these experiments are described in terms of their objectives, procedures, mission profile requirements, and spacecraft systems requirements.

Varying degrees of detail are required in the experiment definition documentation. In early stages, only the more gross aspects of the experiments need be considered, adhering to a quasi- "management-by-exception" principle. These "first-cut" experiment descriptions may be in broad terms which allow only the determination of such factors as: a) whether the experimental apparatus can be available at the time of the flight, b) whether the necessary orbit altitude and inclination agree with the planned orbit, c) whether gross conflicts exist between experiment support required from subsystems, and d) capabilities of expected vehicle subsystems. Other "go-no-go" criteria which might preempt an experiment from a given flight include: inadequate mission lifetime, inadequate extravehicular engineering activity (EVEA), and inadequate crew support availability in time or skill.

After the first screening, experiment descriptions should be in terms of preliminary specifications, and be written in increasing levels of detail as the payload plan begins to take shape, and the more subtle constraints and interferences become known.

To organize this increasing detail of interrelationship between the functions of a system and its implementation hardware, new systems analysis techniques have been developed (Ref. 3 and 4). One technique is specifically oriented toward product functional analysis, and provides a logical model and graphical portrayal of a system's functions and hardware. In addition, it provides direction for inclusion of appropriate technical data in each of the various specification levels of the system. Thus, it establishes a baseline for technical management control of the system development process. This functional analysis model also yields the system specification tree and therefore is named FAST (Functional Analysis and Specification Tree).

In applying the techniques of FAST model generation, a uniform process is followed on an interrative basis which is:

(a) Objectives of the flight (or system) are stated as functions,

(b) Subfunctions are defined and stated in relationship to accomplishment of each system function,

(c) The process of (b) is repeated as necessary until definition of a first (gross) hardware concept for implementation occurs.

Figure 3 illustrates this process. Note in the above paragraph that the relationship of (a) to (b) differs from that of (b) to (c). The FAST technique demands that the transition from a function to its concept of hardware implementation always be illustrated by a 90-degree turn in the portrayal. It is these turns which provide the direction for the scope of specification preparation and subsequent base-line control.

In large systems it is the usual case for functions, such as f_2 and f_n of Figure 3, to be expanded and developed by different organizations. Thus, each developer could conceive of similar concepts for hardware implementation. Preparation of the FAST portrayal, and comparison of the illustrated functions of each hardware concept will indicate commonality and possible redundancy of concept. In consequence only one concept would be selected to carry out the similar functions. Such a selection is illustrated by the dotted intersections between HC1 (hardware concept 1) and both f_2 and f_n of Figure 3.

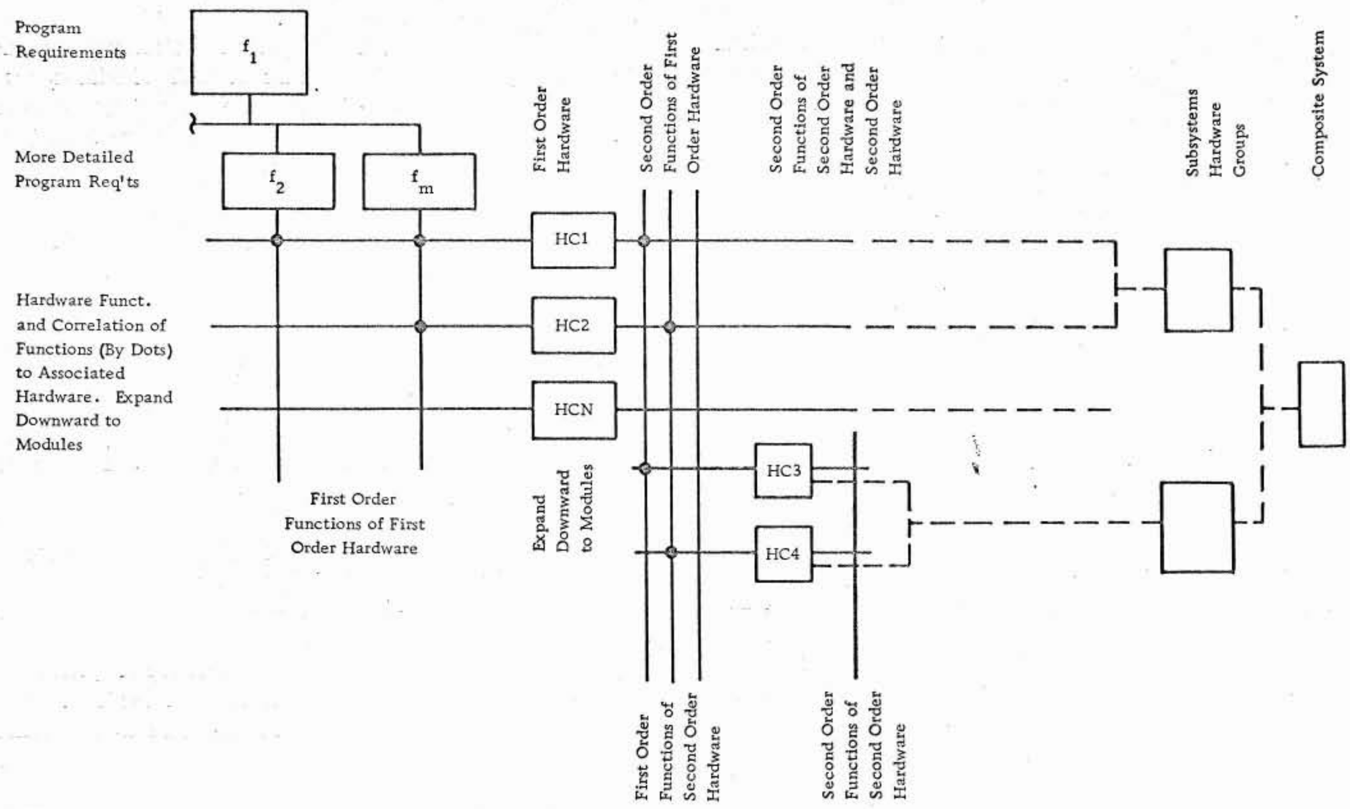


Figure 3. Functional Analysis Specification Tree (FAST) Evolution Format

The preceding illustration concerned commonality between a hardware and multiple functions. FAST portrayal also defines commonality between a function and multiple hardwares. This is shown by the intersecting dots at f_n and HC1 and HC2 of Figure 3. Explicit definition of such commonalities is essential to the achievement of maximum performance by optimum design, subsequent assessment of failure effects, and alternate modes of operation.

The FAST technique also illustrates how a system's functions grow beyond those originally recognized at system inception. For example, an initial function "to provide guidance" may result in the definition of an inertial guidance hardware concept. However, due to the selection of a guidance platform design, which includes gas bearings, a new function is established (i.e., "Provide an air bearing supply.") Since this new function does not directly provide a useable output recognizable as one of the system or flight functions, it is termed a "second-order" function. Such functions are illustrated in Figure 3, eminating from HC1 and HC2. Note that these second-order hardware (HC1, HC2 and HCn are first-order hardware) become the first-order functions for second-order hardware (HC3 and HC4). The development of FAST for these second-order hardwares follows a process identical to that employed for the first-order hardware. Such an organized method for the development of experiment and system definitions allows the activity to be broken into clearly identified and nonoverlapping portions for task assignments to departments or subcontractors. It also provides for the use of computer techniques in monitoring the program schedule, budget, etc. The final set of experiment and system specifications provides the required procurement information for contract end items. An example of FAST, as applied to an experiment, is given in Figure 4.

Early internal communication among principal investigator, cognizant agency, payload integrator, and hardware supplier in this formal FAST language, will enable transition from conceptual flight plans to final procurement specifications.

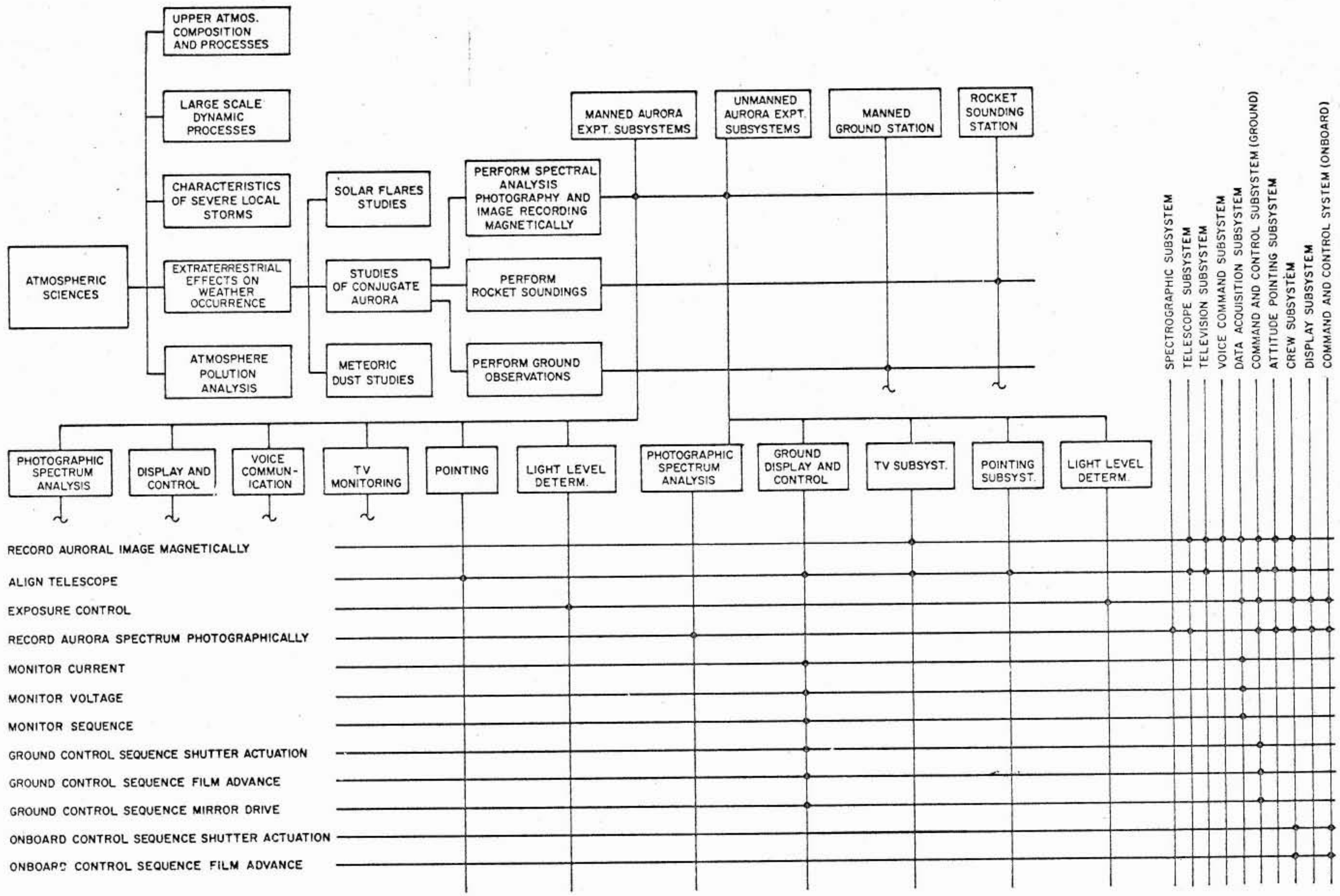


FIGURE 4. EXAMPLE OF THE FAST TECHNIQUE AS APPLIED TO AN EXPERIMENT

3. Commonality Matrix (C-Matrix)

The principal purpose of a commonality matrix is identification of similarities between equipment requirements for the group of experiments under consideration — with the objective of removing as much duplication as possible. Figures 5 and 6 show a typical C-matrix for a selected number of experiments similar to those which have been suggested for AAP [2]. Several benefits may be derived from its use. In selecting experiments to be flown together, the equipment commonality matrix may be used, first, to indicate which experiments should be grouped together because of similar equipment lead times, compaction of experimental apparatus requirements, etc. Second, the instruments may be investigated for similarity with the purpose of identifying instruments which can satisfy measurement requirements for which a different instrument has been specified. This can also be used to suggest the desirability of modifying an instrument allowing its use to satisfy measurement requirements for more than one experiment. Third, the commonality matrix may be used to identify the categories and ranges of instruments required for the total program so that vehicle hardware may be designed to furnish support generally when specific experiment groupings are yet undetermined. Fourth, the nature of the scientific apparatus is often indicative of crew skill requirements. This fact may be used to assist in the groupings of experiments to minimize the diversity of crew skill and training requirements. Finally, the commonality matrix of experiments versus their required equipment may help in the identification of the most important, limiting, or constraining instrumentation requirements, thereby simplifying the problem by eliminating the trivial from consideration.

The C-matrix may be applied at two levels. A gross C-matrix may be developed prior to the grouping of experiments into flight packages. It should contain all major experiments which are likely to present integration problems, and it should display only the instruments and support requirements which will be needed for optimizing the grouping into flight packages. In addition, there may be many special C-matrices, one for each flight, after payload packages have been assembled. These should contain all experiments on the flight and more details about the instruments. They should serve to optimize the integration for this specific flight.

4. Flight Matrix (F-Matrix)

The flight matrix, Figure 7, displays all the experiments planned for a program versus the expected flight schedule and orbital parameters. Indicated also, are anticipated rendezvous. The matrix, shown in Figure 7, is only a section out of a much larger matrix. A full-scale matrix for the AAP (earth orbital phase), ranging over two printed pages and indicating exactly 100 experiments, has been published recently [2]. The flight matrix allows the determination of experiments which could be grouped on a common flight, considering factors such as: a) experiment position relative to the earth, moon, ground station, etc., b) whether the flight path takes the experiment over a given point on earth repetitiously, or whether it "scans" the earth, c) how much time the experiment can spend in darkness or light, d) what radiation levels may be anticipated from the flight path and duration, e) what rendezvous services may be used, such as film or culture pickup, etc.

By minimizing the variety of STAs required by experiments on a given flight, crew skills may be kept within reasonable bounds, and more narrowly trained specialists used to advantage. Such an approach classifies the flight by technology area, and stresses that area in selection of experiments.

The flight matrix may also be used to sequence the experiments chronologically so that prerequisite or precursor experiments may be performed early enough to provide the results needed for design of later experiments. Such sequencing must be performed both within and between flights.

Cross correlation of the flight matrix and the equipment commonality matrix allows the compilation of experimental apparatus required for a given flight. This plot identifies equipment which can be shared and provides constraining information relative to which experiments can be conducted simultaneously.

The flight matrix is primarily required for the payload grouping function in Figure 1. A duplicate is used for the new payload plan function, so that any suggestions for reassignments or any selection of alternate experiments may be simultaneously recorded at both places.

5. Load Matrix (L-Matrix)

The load matrix plots the experiments for a particular flight versus all the subsystems and auxiliary functions needed to perform the experiments. Thus, a separate load matrix is required for each flight. It should contain the best available information regarding demands imposed on each subsystem or function by the experiment.

A simple load matrix, which presents steady-state experiment demands on the vehicle, may be used to sum the requirements of over-all weight, power, thermal conditioning, etc., for all experiments for comparison with the total vehicle capability and subsystem capability in each respect. This is of interest during an early phase experiment grouping to identify gross incompatibilities, but the most limiting constraints are not identifiable until the time-dependent experiment requirements are matched against the time-dependent subsystem and crew availabilities. While manual methods can be used to rough out the problem,

EXPERIMENT SUPPORT EQUIPMENT

CLASS OF SUPPORT EQUIPMENT →		DATA STORAGE			COMMUNICATIONS UNITS								GUIDANCE NAVIGATION				STRUCTURAL UNITS						THERMAL UNITS				INSTRUMENT SUPPORT			EVEA SUPPORT									
LEAD TIME FOR PROCUREMENT IN MONTHS →		18	8	10	16	12	15	8	12	10	6-10	12	18	22	18	14	8	18	8	12	16-24	12	6	24-32	14		4	7	18	18	18	18	14	18	12	5	6-12	8-15	12-20
TYPE OF EQUIPMENT		TAPE RECORDERS	PLOTTERS	MEMORY DEVICES	RADAR ANTENNAS	WIDEBAND ANTENNAS	TRANSMITTERS	RECEIVERS	CLOSED CIRCUIT TV	LASER MODULATOR, DEMOD	CONTROL UNITS	DISPLAY UNITS	ALTIMETER RADAR	COHERENT IMAGING RADAR	NON-COHERENT IMAG. RAD.	SEARCH AND TRACK RADAR	WINDOWS	AIRLOCKS	BOOMS	ANTENNA STRUCTURES	GIMBALLED PLATFORM	SPEC. EXPERIM. STRUCTURES	THERMOSTATS	CRYOGENIC SYSTEMS	THERMO REGULATING SYST.	POINTING SYSTEMS	ILLUMINATORS	FLAT SURFACE PLATES	MIRROR ASSEMBLY AND ACC.	A.M.U. (ASTRON, MANEUVER)	A.M.U. CHECKOUT SYSTEM	A.M.U. STORAGE RACK	EVEA TOOLS	LOCOMOTION EQUIPMT	EVA MEASURG & MONITI. SYST	EVEA TASK BOARDS	ELECTRIC SUPPORT	LIFE SUPPORT	OTHER SUPPORT
STA	EXPERIMENT TITLE																																						
ADV. SUBSYSTEMS	OPTICAL COMMUNICATIONS	●								●	●	●									●		●	●		●			●								●		
ADV. LIFE SUPPORT	CABIN ATMOSPHERE																																					●	
	FLUID MANAGEMENT TECHNOLOGY																																						●
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS																	●				●								●	●	●	●	●	●				
	MAINTENANCE AND REPAIR TECHNIQUES																													●	●	●	●	●	●	●			
	CAPTURE OF SYNCOM 3				●											●				●										●	●	●							●
SPACE MEDICINE	PULMONARY FUNCTION																																						●
	THERMAL REGULATION IN MAN											●													●														
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY																										●												●
	CAPILLARITY STUDY																										●	●											
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE								●		●										●																		●
	X-RAY ASTRONOMY																				●	●																	
	MANNED SOLAR OBSERVATORY								●		●										●	●																	
EARTH SCIENCES	SYNOPTIC EARTH MAPPING	●		●	●	●	●	●			●									●																			
	MULTI-FREQUENCY RADAR IMAGERY				●		●	●				●	●	●						●																			
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS	●	●				●	●	●															●															
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER	●																																					
	CONJUGATE AURORA	●																					●														●		
LUNAR ORBIT	METEORITE DUST ANALYSIS																●		●																				
	LUNAR RADIO FREQUENCY REFLECTIVITY					●	●	●												●																			
	LUNAR PHOTOGRAPHY												●																										
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT																																						
	SAMPLE ANALYSIS ON LUNAR SURFACE																																						

FIGURE 6. COMMONALITY MATRIX, SUPPORT EQUIPMENT

INSTRUMENTS AND EXPERIMENTAL EQUIPMENT — SYNOPTIC INSTRUMENTS

STA	EXPERIMENT TITLE	TELESCOPES (12–38 IN.)	MICROSCOPES	ULTRA HIGH RESOL. CAMERA	CARTOGRAPHIC CAMERA	IR IMAGER	MULTI-SPECTRAL IMAGER	MICROWAVE IMAGER	MICROWAVE RADIOMETER
LEAD TIME FOR PROCUREMENTS IN MONTHS		24–32	16	24	20	27	25	36	30
ADV. SUBSYSTEMS	OPTICAL COMMUNICATIONS	●							
ADV. LIFE SUPPORT	CABIN ATMOSPHERE								
	FLUID MANAGEMENT TECHNOLOGY								
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS								
	MAINTENANCE AND REPAIR TECHNIQUES								
	CAPTURE OF SYNCOM 3								
SPACE MEDICINE	PULMONARY FUNCTION								
	THERMAL REGULATION IN MAN								
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY								
	CAPILLARITY STUDY		●						
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE	●	●						
	X-RAY ASTRONOMY								
	MANNED SOLAR OBSERVATORY								
EARTH SCIENCES	SYNOPTIC EARTH MAPPING							●	●
	MULTI FREQUENCY RADAR IMAGERY								
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS	●				●	●	●	●
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER	●							
	CONJUGATE AURORA	●					●		
LUNAR ORBIT	METEORITE DUST ANALYSIS								
	LUNAR RADIO FREQUENCY REFLECTIVITY								
	LUNAR PHOTOGRAPHY	●		●	●		●		
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT								
	SAMPLE ANALYSIS ON LUNAR SURFACE								

ANALYTIC INSTRUMENTS

STA	EXPERIMENT TITLE	IR SPECTROMETER	WHITE LIGHT CORONOGRAPH	UV – SPECTROGRAPH	UV – SPECTRO HELIOGRAPH	X-RAY ANALYZERS	GAMMA RAY SPECTROMETER	PROTON-ELECTRON SPECTROMETER	ALPHA SCATTERING SPECTROMETER	NEUTRON SCATTERING SPECTROMETER	NEUTRON ACTIVATION ANALYZER	MASS SPECTROMETER	GAS ANALYZER
LEAD TIME FOR PROCUREMENTS IN MONTHS		26	18	20–26	24	18–24	12	16	14	16	18	12	6
ADV. SUBSYSTEMS	OPTICAL COMMUNICATIONS												
ADV. LIFE SUPPORT	CABIN ATMOSPHERE												
	FLUID MANAGEMENT TECHNOLOGY												
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS												
	MAINTENANCE AND REPAIR TECHNIQUES												
	CAPTURE OF SYNCOM 3												
SPACE MEDICINE	PULMONARY FUNCTION												●
	THERMAL REGULATION IN MAN												
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY												
	CAPILLARITY STUDY												
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE												
	X-RAY ASTRONOMY					●							
	MANNED SOLAR OBSERVATORY		●	●	●	●							
EARTH SCIENCES	SYNOPTIC EARTH MAPPING												
	MULTI FREQUENCY RADAR IMAGERY												
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS	●											
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER	●		●									
	CONJUGATE AURORA							●					
LUNAR ORBIT	METEORITE DUST ANALYSIS												
	LUNAR RADIO FREQUENCY REFLECTIVITY												
	LUNAR PHOTOGRAPHY												
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT						●						
	SAMPLE ANALYSIS ON LUNAR SURFACE			●					●	●	●	●	

MONITORING INSTR. AND TRANSDUCERS

STA	EXPERIMENT TITLE	PHOTOMETER	MASS FLOW METER	MAGNETOMETER	ACOUSTIC PARTICLE DETECTOR	TELE-THERMOMETER	PRESSURE TRANSDUCERS
LEAD TIME FOR PROCUREMENTS IN MONTHS		6	6	18	18	6	4
ADV. SUBSYSTEMS	OPTICAL COMMUNICATIONS						
ADV. LIFE SUPPORT	CABIN ATMOSPHERE						●
	FLUID MANAGEMENT TECHNOLOGY						
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS					●	●
	MAINTENANCE AND REPAIR TECHNIQUES						
	CAPTURE OF SYNCOM 3						
SPACE MEDICINE	PULMONARY FUNCTION		●				
	THERMAL REGULATION IN MAN					●	
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY						
	CAPILLARITY STUDY						
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE	●					
	X-RAY ASTRONOMY						
	MANNED SOLAR OBSERVATORY						
EARTH SCIENCES	SYNOPTIC EARTH MAPPING						
	MULTI FREQUENCY RADAR IMAGERY						
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS						
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER						
	CONJUGATE AURORA			●			
LUNAR ORBIT	METEORITE DUST ANALYSIS				●		
	LUNAR RADIO FREQUENCY REFLECTIVITY						
	LUNAR PHOTOGRAPHY						
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT						
	SAMPLE ANALYSIS ON LUNAR SURFACE						

SPECIAL BIO-INSTRUMENTS

STA	EXPERIMENT TITLE	CO_2 REMOVAL AND RED. INSTR.	OXIDATION OF HYDRAC. SUBS.	HYDROGEN-PEROX. DECOMP. SYST.	EAR CANAL THERMISTOR	HARNESS WITH 12 THERMISTORS	PRESSURE SUIT
LEAD TIME FOR PROCUREMENTS IN MONTHS		15	18	18	6	8	12
ADV. SUBSYSTEMS	OPTICAL COMMUNICATIONS						
ADV. LIFE SUPPORT	CABIN ATMOSPHERE	●	●	●			
	FLUID MANAGEMENT TECHNOLOGY						
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS						
	MAINTENANCE AND REPAIR TECHNIQUES						
	CAPTURE OF SYNCOM 3						
SPACE MEDICINE	PULMONARY FUNCTION						
	THERMAL REGULATION IN MAN				●	●	●
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY						
	CAPILLARITY STUDY						
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE						
	X-RAY ASTRONOMY						
	MANNED SOLAR OBSERVATORY						
EARTH SCIENCES	SYNOPTIC EARTH MAPPING						
	MULTI FREQUENCY RADAR IMAGERY						
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS						
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER						
	CONJUGATE AURORA						
LUNAR ORBIT	METEORITE DUST ANALYSIS						
	LUNAR RADIO FREQUENCY REFLECTIVITY						
	LUNAR PHOTOGRAPHY						
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT						
	SAMPLE ANALYSIS ON LUNAR SURFACE						

GENERAL LAB. INSTR.

STA	EXPERIMENT TITLE	PURITY DETERM. EQUIPMENT	LIQUID STORAGE AND TRANST. DEV.	BLADDERS, CAPILLARIES, ETC.	DROPPERS AND LIQUID SUPPLY
LEAD TIME FOR PROCUREMENTS IN MONTHS		12	114	14	7
ADV. SUBSYSTEMS	OPTICAL COMMUNICATIONS				
ADV. LIFE SUPPORT	CABIN ATMOSPHERE				
	FLUID MANAGEMENT TECHNOLOGY	●			
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS				
	MAINTENANCE AND REPAIR TECHNIQUES				
	CAPTURE OF SYNCOM 3				
SPACE MEDICINE	PULMONARY FUNCTION				
	THERMAL REGULATION IN MAN				
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY		●		
	CAPILLARITY STUDY			●	●
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE				
	X-RAY ASTRONOMY				
	MANNED SOLAR OBSERVATORY				
EARTH SCIENCES	SYNOPTIC EARTH MAPPING				
	MULTI FREQUENCY RADAR IMAGERY				
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS				
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER				
	CONJUGATE AURORA				
LUNAR ORBIT	METEORITE DUST ANALYSIS				
	LUNAR RADIO FREQUENCY REFLECTIVITY				
	LUNAR PHOTOGRAPHY				
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT				
	SAMPLE ANALYSIS ON LUNAR SURFACE				

SPEC. EXPMTL. SUBSYSTEMS

STA	EXPERIMENT TITLE	CHLORATE CANDLE	ELECTROLYSIS CELLS	WATER RECLAMATION SYST.	STANDARD CAMERAS, FILM	STAGE FOR CONTRAST PHOTOGR.
LEAD TIME FOR PROCUREMENTS IN MONTHS		15	15	12–18	2–6	12
ADV. SUBSYSTEMS	OPTICAL COMMUNICATIONS					
ADV. LIFE SUPPORT	CABIN ATMOSPHERE	●	●			
	FLUID MANAGEMENT TECHNOLOGY		●	●		
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS					
	MAINTENANCE AND REPAIR TECHNIQUES				●	
	CAPTURE OF SYNCOM 3				●	●
SPACE MEDICINE	PULMONARY FUNCTION					
	THERMAL REGULATION IN MAN					
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY				●	
	CAPILLARITY STUDY				●	●
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE				●	
	X-RAY ASTRONOMY					
	MANNED SOLAR OBSERVATORY				●	
EARTH SCIENCES	SYNOPTIC EARTH MAPPING				●	
	MULTI FREQUENCY RADAR IMAGERY				●	
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS					
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER					
	CONJUGATE AURORA				●	
LUNAR ORBIT	METEORITE DUST ANALYSIS					
	LUNAR RADIO FREQUENCY REFLECTIVITY					
	LUNAR PHOTOGRAPHY				●	
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT					
	SAMPLE ANALYSIS ON LUNAR SURFACE					

FIGURE 5. COMMONALITY MATRIX, INSTRUMENTS

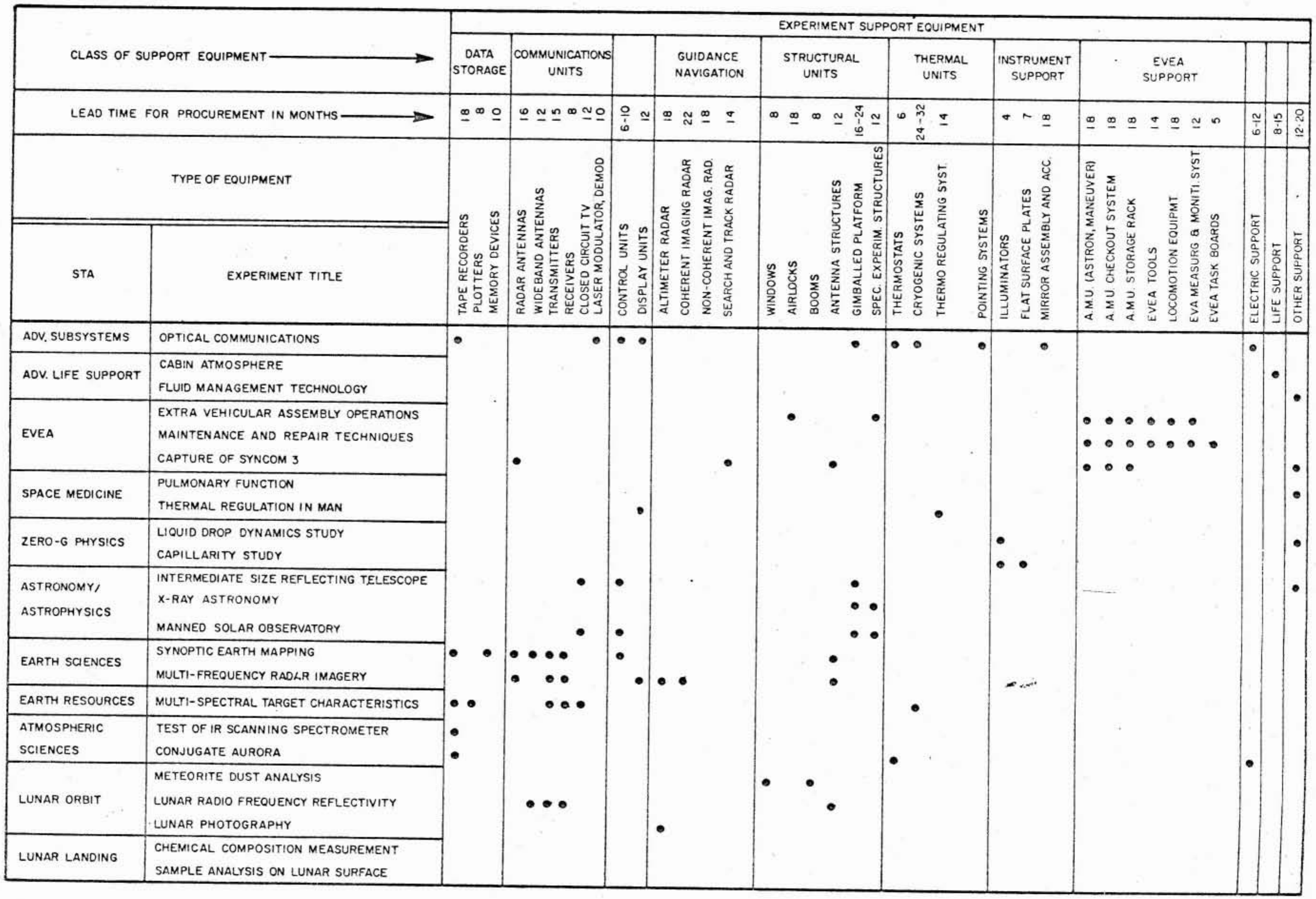


FIGURE 6. COMMONALITY MATRIX, SUPPORT EQUIPMENT

YEAR IN THE PROGRAM	FIRST			SECOND						THIRD									FOURTH						
FLIGHT: E = EARTH ORBIT, L = LUNAR	E_1	E_2	E_3	E_4	E_5	E_6	E_7	L_1	E_8	L_2	L_3	E_9	E_{10}	L_4	E_{11}	E_{12}	L_5	L_6	E_{13}	L_7	E_{14}	E_{15}	E_{16}	L_8	L_9
ALTITUDE: L = 200 nm. S = SYNCHR.	L	L	L	L	S	L	L	·	L	·	·	L	S	·	L	L	·	·	L	·	L	L	L	·	·
INCLINATION: I = 28.5° P = POLAR	I	I	I	P	·	I	I	·	P	·	·	I	·	·	I	I	·	·	P	·	I	I	I	·	·
DURATION IN DAYS	14	14	14	14	14	14	14	28	45	14	14	45	45	28	45	45	14	14	45	28	45	45	45	14	14
X = SAT IB; O = SAT V H = RENDEZVOUS	X	X	X	O	O	X	X	O	O	O	O	X	O	O	O	O	O	O	O	O	O	X	X	O	O
PRINCIPLE MISSION OF EACH FLIGHT	CHECK-OUT	ENVIRONMENT TEST	PHYSICAL SCIENCES	CHECK-OUT FOR LUNAR PR	MAN IN SYNCHR. ORBIT	RENDEZVOUS	RESUPPLY	LUNAR EXPLORATION	ATMOSPHERIC SCIENCES	FIRST EXTENDED	LUNAR LANDING	BIO-SCIENCES	OPERATIONS IN SYNCHR O.	LUNAR EXPLORATION	FIRST 90 DAY STAY	RESUPPLY FLIGHT	LUNAR SURFACE	EXPLORATION	EARTH RESOURCES FI	LUNAR EXPLORATION	ASTRO SCIENCES	135 DAYS WITH	TWO RESUPPLIES	LUNAR SCIENCES	

EXPERIMENT IS EXCLUDED FROM: (SHADED AREAS)

STA	EXPERIMENT TITLE	LOW INCLINED EARTH ORBIT	POLAR EARTH ORBIT	HIGH SYNCHRONOUS EARTH ORBIT	LUNAR ORBIT	LUNAR LANDING
ADV. SUBSYSTEM	OPTICAL COMMUNICATIONS	shaded	shaded		shaded	shaded
ADV. LIFE SUPPORT	CABIN ATMOSPHERE					shaded
	FLUID MANAGEMENT TECHNOLOGY					
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS				shaded	shaded
	MAINTENACE AND REPAIR TECHNIQUES				shaded	shaded
	CAPTURE OF SYNCOM 3	shaded	shaded		shaded	shaded
SPACE MEDICINE	PULMONARY FUNCTION					
	THERMAL REGULATION IN MAN					
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY					shaded
	CAPILLARITY STUDY					shaded
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE					shaded
	X-RAY ASTRONOMY					
	MANNED SOLAR OBSERVATORY				shaded	
EARTH SCIENCES	SYNOPTIC EARTH MAPPING			shaded	shaded	shaded
	MULTI-FREQUENCY RADAR IMAGERY			shaded	shaded	shaded
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS			shaded	shaded	shaded
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER			shaded	shaded	shaded
	CONJUGATE AURORA	shaded	shaded		shaded	shaded
LUNAR ORBIT	METEORITE DUST ANALYSIS	shaded	shaded	shaded		shaded
	LUNAR RADIO FREQUENCY REFLECTIVITY	shaded	shaded	shaded		shaded
	LUNAR PHOTOGRAPHY	shaded	shaded	shaded		shaded
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT	shaded	shaded	shaded	shaded	
	SAMPLE ANALYSIS ON LUNAR SURFACE	shaded	shaded	shaded	shaded	

STA	EXPERIMENT TITLE	E_1	E_2	E_3	E_4	E_5	E_6	E_7	L_1	E_8	L_2	L_3	E_9	E_{10}	L_4	E_{11}	E_{12}	L_5	L_6	E_{13}	L_7	E_{14}	E_{15}	E_{16}	L_8	L_9
ADV. SUBSYSTEM	OPTICAL COMMUNICATIONS													•												
ADV. LIFE SUPPORT	CABIN ATMOSPHERE																					•				
	FLUID MANAGEMENT TECHNOLOGY			•																						
EVEA	EXTRA VEHICULAR ASSEMBLY OPERATIONS			•																						
	MAINTENACE AND REPAIR TECHNIQUES			•																						
	CAPTURE OF SYNCOM 3													•												
SPACE MEDICINE	PULMONARY FUNCTION			•			•		•	•	•		•	•		•						•				
	THERMAL REGULATION IN MAN				•		•			•																
ZERO-G PHYSICS	LIQUID DROP DYNAMICS STUDY						•																			
	CAPILLARITY STUDY			•													•									
ASTRONOMY/ ASTROPHYSICS	INTERMEDIATE SIZE REFLECTING TELESCOPE																					•				
	X-RAY ASTRONOMY						•															•				
	MANNED SOLAR OBSERVATORY																					•				
EARTH SCIENCES	SYNOPTIC EARTH MAPPING									•						•				•						
	MULTI-FREQUENCY RADAR IMAGERY									•						•				•						
EARTH RESOURCES	MULTI-SPECTRAL TARGET CHARACTERISTICS															•				•						
ATMOSPHERIC SCIENCES	TEST OF IR SCANNING SPECTROMETER									•						•				•						
	CONJUGATE AURORA					•																				
LUNAR ORBIT	METEORITE DUST ANALYSIS								•												•					
	LUNAR RADIO FREQUENCY REFLECTIVITY														•											
	LUNAR PHOTOGRAPHY								•						•						•					
LUNAR LANDING	CHEMICAL COMPOSITION MEASUREMENT										•							•								
	SAMPLE ANALYSIS ON LUNAR SURFACE										•														•	

FIGURE 7. FLIGHT MATRIX

a computer program, EXOTIC (Experiment Operation and Test Integration Concept) has been developed to do the detailed scheduling of crew time, crew skills, power, etc.

The EXOTIC program is used in a computer technique to test experiment demands against spacecraft and orbital constraints. The program is of greatest value in scheduling allocation of time-dependent expendables such as crew manpower and skill, power, thermal conditioning, data handling, etc. Allocation of space, weight, and other characteristically static expendables may be accomplished without difficulty by other means. EXOTIC does not function as a simulation and is therefore unsuited to such applications as the determination of mission success probabilities as functions of perturbations artificially injected into the mission scenario.

In use, the program is fed a series of experiments sequenced in the desired order of examination. The first experiment on the list is examined by the program to determine crew time, crew skill, and power requirements. These three time-dependent expendables are used for purposes of this example; however, different and/or more such expendables may be written into the program. The requirements are examined with respect to the comparable subsystem and crew availabilities at the moment of interest in the flight. If the required crew is not occupied with sleeping, eating, housekeeping, operating other experiments, etc., and the required power is available, the experiment will be scheduled. If, however, the requirements for skilled crew members and power are unavailable to accommodate the particular experiment at the moment of interest, the program will examine the next listed experiment to determine if those demands can be satisfied. The program will continue iterating the above process until all experiments requiring crew and power availabilities are scheduled. In doing this, the program notices the termination of a previous experiment and looks for the next experiment on the list which can be accommodated by the new level of crew time, crew skill, and power availability. As a sub-routine to the program, an ephemeris tape can be used to provide a scenario of land masses, day-night situations, etc. Another feature of the program is the "look-ahead" function which provides the capability to look into future required activities determining setup and warmup time and power, expected crew availability, etc., to add such preparatory requirements to the operational requirements at the moment of interest. A forcing function is used in the "look-ahead" program to prevent the senseless warmup of a future experiment, when projected shortage of any expendable prevents scheduling to completion. Another forcing function may be used to schedule an experiment which would otherwise be completely excluded. A forcing function may also be employed to constrain the scheduling of experiments having orbit dependencies, such as position over ground stations. The latitude allowed by the program, in scheduling the beginning of eating or sleeping periods, is limited by forcing functions which prevent the computer from taking unfair advantage of the astronauts.

A third concept of the program (EXOTIC III) would be run on the ground during a flight, working in real time to alter the experiment schedule as required by contingencies.

Another computer program (VECTOR), has been designed to facilitiate allocation of resources by computer methods. This program uses trade ratios between expendables so that each expendable may be represented by the length of a vector. Planes of the vector represent various expendables. (See Figure 8.) By adding vectors head to tail in three or more axes (such as power, weight, and volume), the total subsystem requirements of all experiments may be added (Figure 9) and compared to the vehicle's capability through the use of machine methods.

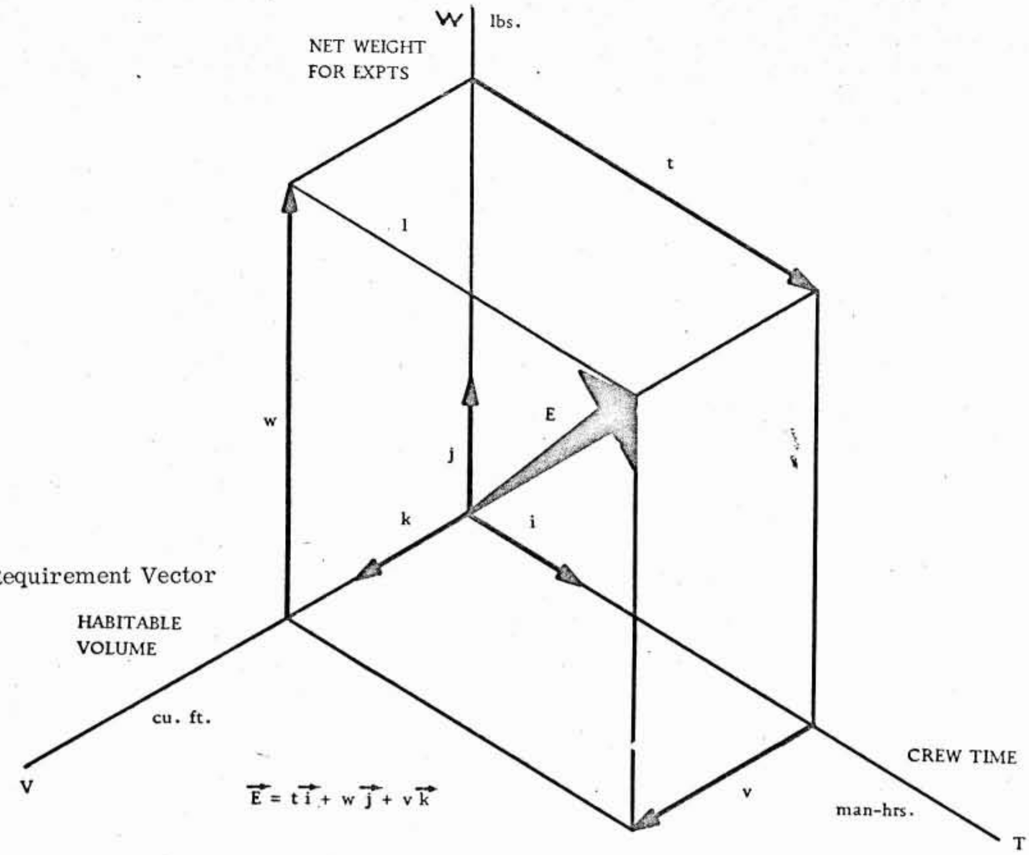
Both of these machine methods help in narrowing the problem of generating a load matrix; however, it must be emphasized that there is no substitute for the human mind in the final interpretation of the matrix and in the formulation of payload integration conclusions. Preliminary conclusions provided by an analysis of the load matrix should be compared with conclusions reached with the commonality and flight matrices to arrive at reassignments of experiments to flights in an iterative approach to a final complement of experiments in the integrated payload (new payload plan).

6. Experiment/Spacecraft/Ground System Interfaces

Before finalizing the new payload plan, the integrator must define the exact position of vital interfaces. This is necessary so that specifications can be written and responsibilities assigned. Important interfaces exist between the experiment and the standard spacecraft hardware, and in some areas, between the experiment and the ground system. There is naturally, in all cases, an important interface between the spacecraft and the ground system.

In many instances the location of the interface should be determined by trade studies showing simplification of the payload through greater utilization of common equipment. The sensitivity of payload optimization to the location of interfaces may be shown in a specific example of the experiment/spacecraft interface.

Experience has shown that many experiments require television for such applications as telescope pointing, readout of spark chambers, observation of EVEA, etc. In this obvious example, the interface of the shared television system should be at the input of



$$\vec{E} = t\,\vec{i} + w\,\vec{j} + v\,\vec{k}$$

Figure 8. Experiment Requirement Vector

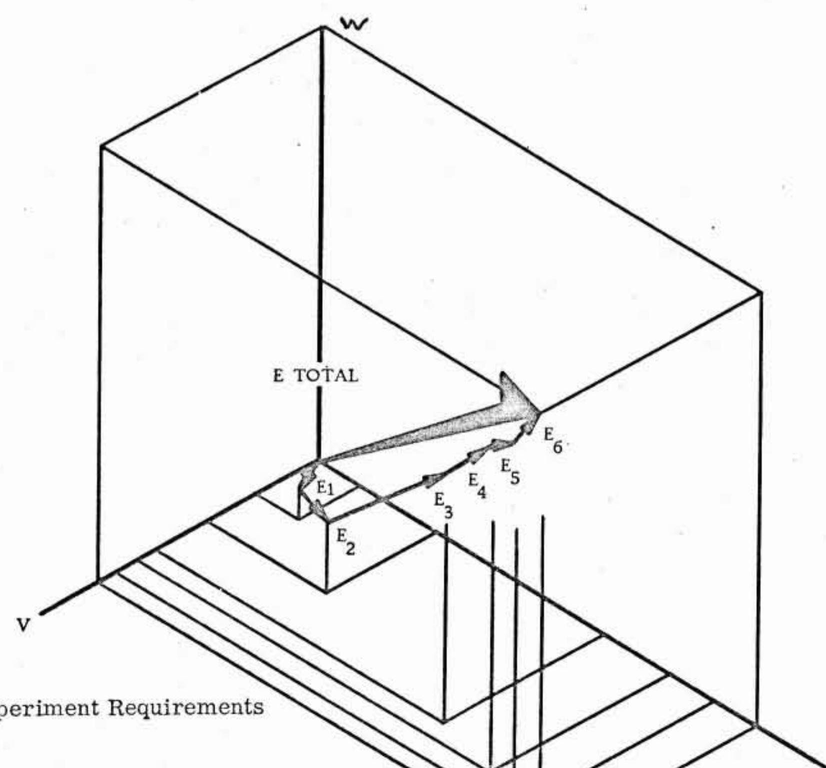


Figure 9. Vector Addition of Individual Experiment Requirements

$$E_{TOTAL} = E_1 + E_2 + E_3 + E_4 + E_5 + E_6$$

the main video amplifier. This will enable the sharing of the synchronizing generator, transmitter, modulator, power supplies, high level video amplification, control equipment, monitors, tape recording, etc. Moving this interface to the output of the vidicon tube could save a video preamplifier and line driver, but the interference problems would outweigh the benefits.

In a similar way, the sharing of equipment by judicious selection of the interface location can be applied in optical experiments by sharing high voltage supplies and coincidence circuits for photomultiplier tubes, sharing gimbals for telescopes, sharing temperature control systems for optics, etc. Still more obvious is the manner in which communications links, data storage systems, etc., can be shared. Sharing of telemetry signal conditioning equipment can benefit from the use of programmable gain setting equipment which automatically adjusts the signal conditioning equipment to suit the particular sensor in use.

At times the selection of the appropriate interfaces between the experiment, the vehicle subsystems, and the ground equipment must be made while recognizing the changing conditions in the launch sequence. Integration of a radioisotope thermoelectric generator illustrates the point (Ref. 5). The radioisotopic material provides a constant (over short periods) amount of heat which must be transferred away from the fuel block. During the ground checkout prior to launch, cooling may be furnished through umbilical connections from ground support equipment. When the umbilical is dropped, a water boiler is a practical way of carrying the heat away from the block because the launch time is relatively short and the few pounds of water required pose a negligible weight penalty. After attaining orbit, a radiative system must be used because sufficient water cannot be carried for protracted cooling. Fortunately, advantage may be taken of the fact that the vehicle structure has no further requirement to sustain large mechanical loads and, consequently, the skin can be used as a radiator, elevating the temperature to a point which would otherwise compromise structural integrity.

The eventuality of abort must also be considered in the location of interfaces. Continuing with the radioisotope thermoelectric generator example, provisions must be made for ejection of the fuel block in the event of abort, because the water boiler will only function until the water is depleted and the radiative mode of cooling will not come into operation at all. Further, provisions should be made to cool the ejected fuel block to prevent melt-down and possible spread of contamination.

At times the trade studies necessary to locate the interface for maximum utilization of equipment may become very complex. For example, is it simpler to bring cryogenic connections from a shared cooling system through a multiaxis gimbal to cool an infrared detector or should separate Peltier coolers be used?

Another interesting interface is seen in optical communications experiments, where highly instrumented ground stations are required. These must be in line of view, located in a geographical area with minimum cloud cover (desert area).

Each design case for the location of system interfaces must be weighed separately, and no formula can be given to arrive at the answer straightforwardly; however, factors to be considered include:

a) Suitability of equipment for sharing (with or without modifications to enhance suitability),

b) Simultaneous requirements for equipment to be shared (which tend to discourage sharing),

c) Practicality of sharing equipment considering relative locations (long signal paths, etc.),

d) Problems engendered by moving interfaces (RFI, weight, high voltage corona, switching complexity, added load on gimbals, etc.)

e) Improvement or degradation of reliability caused by equipment sharing (less redundancy),

f) Minimization of connections through umbilicals (to stay within specifications or for simplicity),

g) Sensitivity to the mission sequence of events (accessibility, abort, GSE availability, etc.),

h) Attitudes of principal investigators toward possible compromise of their experiment design,

i) Lead times necessary to move interfaces for enhanced utilization of common equipment, and

j) Plans for using the experiment in various groupings, some of which are not suited to sharing of equipment.

CONCLUSION

Space experimentation is entering a highly sophisticated phase of development involving large sections of American industry - each providing support to the growing number of astronauts and to increasingly complex unmanned spacecraft. The space electronics engineers will study many aspects of space science, and scientists will become familiar with engineering subsystems. It is hoped that this paper has contributed to a better understanding of the integration problems in space exploration.

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