

NASA CR-144706

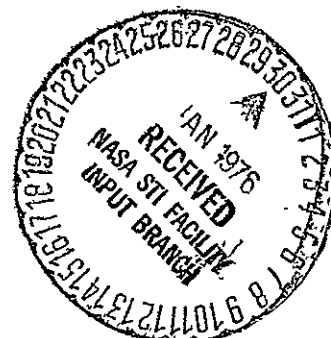
USER BENEFITS AND FUNDING STRATEGIES

J. L. Archer
N. A. Beauchamp
C. F. Day

Stanford Research Institute
306 Wynn Drive, N.W.
Huntsville, Ala. 35805

October 1975
Final Report for Period May through October 1975

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771



STANFORD RESEARCH INSTITUTE
AT HUNTSVILLE, ALABAMA

Copy No. 1

(NASA-CR-144706) : USER BENEFITS AND FUNDING
STRATEGIES Final Report, May - Oct. 1975
(Stanford Research Inst., Huntsville, Ala.)
157 p HC \$6.75

CSCL 05A

N76-15901

Unclas

G3/81 08560

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ABBREVIATIONS

AASIR	Advanced Atmospheric Sounding and Imaging Radiometer
AGA	American Gas Association
AMA	American Medical Association
BP	British Petroleum
°C	degree centigrade
CBS	Columbia Broadcasting System
cm	centimeter
CO ₂	carbon dioxide
COMMUN	Communications
COMSAT	Communications Satellite Corporation
DoD	Department of Defense
DOI	Department of the Interior
DOT	Department of Transportation
EM	electromagnetic
EOS	Earth Observation Satellite
EPA	Environmental Protection Agency
ESA	European Space Agency
EXP	experiment
FCC	Federal Communications Commission
GE	General Electric Company
GHz	gigahertz
GM	General Motors
GSFC	Goddard Space Flight Center
INST	instrument

ABBREVIATIONS (Continued)

IR	infrared
IUS	Interim Upper Stage
kg	kilogram
km	kilometer
lb	pound
m, M	meter
MVAS	Microwave Vertical Atmospheric Sounder
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NO ₂	nitrous oxide
NPD	NASA Policy Directive
NSF	National Science Foundation
OMB	Office of Management and Budget
OPEC	Organization of Petroleum Exporting Countries
PADS	Precision Attitude Determination System
PATTI	Precise and Accurate Time and Time Interval Experiment
R&D	Research and Development
RFI	radio frequency interference
SEOS	Synchronous Earth Observation Satellite
SHF	super high frequency
SO ₂	sulfur dioxide
SRI	Stanford Research Institute
STORMSAT	Storm Satellite
STS	Space Transportation System
UHF	ultrahigh frequency
UN	United Nations
USC	United States Code

ABBREVIATIONS (Continued)

USGS	United States Geological Survey
USPS	United States Postal Service
VISSR	Visible & Infrared Spinscan Radiometer

I INTRODUCTION

A. BACKGROUND

The United States has attained a large measure of maturity in its space programs over the past few years. This is evidenced by the decision to proceed with the development of the Space Transportation System (STS) which provides, through the use of reusable items such as the Shuttle and Space Tug, economical and practical means of orbiting a much larger number of payloads than previously possible. Another, even more significant indication of this maturity is the fact that NASA is not content to define future programs by merely determining what can be done but, rather, what should be done. It is this question that the Hearsh Committee* has addressed at the direction of the Administrator of the National Aeronautics and Space Administration (NASA), James C. Fletcher. The need to provide meaningful answers to this question and an indication of how to answer it were identified by several groups who provided inputs to the Hearsh Committee. Appendix A contains one such input which illustrates several points that many people, both in and out of government, feel should be reflected in NASA's planning activities. The following paragraph presents some of the more important observations made.

It is now evident that the basic attitudes and priorities in this country may not permit large amounts of money to be spent for space spectaculars or space endeavors for purely scientific purposes. In order to obtain support, programs must be structured to improve or maintain the qualities of life, although some purely scientific endeavors should be included. The space endeavors should be selected considering the present needs as well as long-term future needs and requirements. NASA, knowing what can be done in space, should then seek partnerships with the various

* This is the name usually given to the Study Group for NASA's "Outlook for Space" study. Mr. Donald P. Hearsh was named Study Director.

portions of the Federal and State Governments and the private sector that represent and minister to the various needs of man and attempt to work with these organizations to develop space efforts that can favorably impact the quality of life.

The Hearth Committee material that the authors have seen is fully consistent with the philosophy of the previous paragraph. If this philosophy is adopted, then NASA will be structuring many of its programs to be responsive to, and supportive of, the needs and goals of other organizations. This action would have a particular impact on the missions to be flown by the STS since, in the period between 1980 and 2000, this system will be used to orbit most of the payloads.

B. STUDY OBJECTIVE

The Interim Upper Stage (IUS) will be used in conjunction with the Shuttle until the Space Tug becomes available in the middle 1980's. The IUS payloads are, therefore, flown early in the STS era and are among those that will be evaluated by potential users of the STS in their deliberations of whether to participate later in the program. It is important that these payloads be selected to encourage such participation. In the light of the Hearth Committee findings, this specifically means that the IUS payloads should be relevant and highly beneficial to quality of life or scientific needs. The primary objective of the Stanford Research Institute (SRI) study documented in this report is to develop a systematic method whereby IUS payloads can be properly selected. Another objective is to determine viable cost-sharing strategies for the justified payloads in order to maximize the number of IUS payloads (and therefore, the benefits) supportable under a limited NASA budget.

C. METHOD OF APPROACH

To meet the stated study objectives, SRI initiated a NASA-funded study on May 1, 1975 with a three-month period of technical performance and a six-month overall duration. Three tasks were defined to accomplish the desired goals. The specific tasks, as defined originally, were:

- (1) Task 1, Benefit Evaluation - Estimating the benefits for typical payloads.
- (2) Task 2, Payload Ranking - Assigning importance levels to the payloads in Task 1.
- (3) Task 3, Funding and Cost-Sharing Approaches - Determining and evaluating viable funding and cost-sharing alternatives.

The analysis in the study was constrained to consideration of the IUS payloads already identified by General Electric (GE) Company and Fairchild Space and Electronics Company in their on-going studies sponsored by Goddard Space Flight Center (GSFC) to:

- (1) Identify multi-discipline applications payloads for the 1980's that require the Shuttle-IUS geosynchronous orbiting capability;
- (2) Develop concepts for such payloads, treating the Shuttle-IUS combination as a means of providing a test-bed for quick and economical experimentation in space; and
- (3) Identify the technology needed for the implementation of such payloads and concepts.

Early in the study, however, it became evident that the analyses called for in Tasks 1 and 2 would more appropriately be made for individual IUS experiments or instruments than for entire IUS payloads. There were two reasons for this. First, the number of payloads defined and documented by Fairchild and General Electric at the outset of the study was quite small. Second, to determine the benefits attributable to an IUS payload one must first determine those of the individual experiments and instruments.

Subsequently, SRI restructured the original three tasks into four:

- (1) Task 1, Justification of IUS Experiments/Instruments (Benefit Analysis)
- (2) Task 2, Selection Among Justified Experiments (Importance Ranking)
- (3) Task 3, Selection of Payloads
- (4) Task 4, Determination of Funding and Cost-Sharing Approaches

This task breakdown meets the stated study objectives and covers all the activities of the original structure but at the individual experiment level in Tasks 1 and 2 instead of the payload level. This supplements the original task structure by addressing payload synthesis. In each task, the method developed was tested by applying it in case studies. The time and funding constraints limited the research effort primarily to the development of methods and the illustration of the approach using readily available cost and benefit data from existing studies.

The following four sections of this report discuss the results of the four tasks in the revised structure. These discussions are followed by a presentation of the major study conclusions reached in the research effort.

II JUSTIFICATION OF IUS EXPERIMENTS/INSTRUMENTS

A. DEFINITION OF JUSTIFICATION CRITERIA

This study was performed to determine candidate IUS experiments/instruments for IUS payloads and to identify funding strategies for these payloads. Another SRI study^{1,2*} for NASA provided extensive background for this study. In that study, SRI developed techniques for identifying new uses for the STS and developed methods whereby potential users of these STS applications would be identified and subsequently encouraged to sponsor and/or utilize these applications. The current study differs from the previous one in three ways. First, only IUS payloads, not those of the entire STS, are now to be considered. Second, the current study requires a more specific identification of the individual techniques of the methodology than was required in the first study. Third, the current study calls for explicit exercising of the appropriate techniques in order to exhibit examples of IUS uses, appropriately defined IUS payloads, and specific cost-sharing approaches.

Three key criteria identified in the former study^{1,2} will be used for justifying candidate IUS experiments/instruments for possible inclusion on IUS payloads. Although expressed in somewhat different terms than in References 1 and 2, the three critical criteria are as follow:

- (1) In order to be considered for inclusion on an IUS payload, a candidate experiment/instrument must contribute to a recognized goal, need, or objective. It is imperative that the validity of each objective be recognized not only by NASA but also by those outside NASA in order to obtain the required broad support for the IUS program.
- (2) The contribution to each objective must be of sufficient magnitude. The sufficiency test is the determination of whether the candidate experiment/instrument

* Superscript numbers denote references listed at the end of this report.

contributes (either directly, or in the case of an R&D experiment, indirectly through a related operational system*) measurable benefits exceeding the total system life-cycle costs (including R&D, launch, and operating costs). More general benefits criteria will be introduced in Section C.

- (3) If there are alternative experiments/instruments that can perform the same or equivalent function of the candidate IUS experiment/instrument being evaluated, the IUS experiment/instrument being considered must offer the "best" alternative.

The three criteria above (relevance to accepted objectives, benefit sufficiency, and possible non-duplication of effort) would normally be applied in the order given. However, formal application of the first two criteria may be omitted if it is recognized initially that the candidate experiment being considered offers an alternative method for performing the same function as a previously justified experiment. In this case, one need only apply the third criterion to see if the experiment being evaluated can be justified for possible inclusion in an IUS payload. In general, however, all three tests must be made; and in making these tests, many data are generated that are needed in the subsequent operations of ranking IUS experiments by importance, selecting IUS payloads, and evaluating funding strategies. The following discussion shows how these data are generated by applying the criteria for a selected set of cases.

B. ILLUSTRATIVE ANALYSIS

1. Assumptions

In this section, we will illustrate the justification procedure by applying the three criteria defined above to determine a set of justified IUS experiments. We will also display the generated data that have utility in the importance ranking and payload selection operations discussed in

* An operational system is a non-R&D system which is an integral and contributing element in the overall structure set up to perform the day-to-day operations of a user agency. For example, to COMSAT, an operational system is one that can be relied upon to transmit messages or data in response to the demands of COMSAT's customers. Such a system does not merely provide a demonstration of technology for use in an advanced system.

Sections III and IV of this report. To simplify the analysis while sacrificing little of the benefit to be gained from this exercise, the following simplifying assumptions will be made:*

- (1) The accepted objectives to be used in applying the first criterion given in the previous section will be restricted to those identified by the Hearsh Committee. These 37 objectives are grouped under 8 themes (see Appendix B) and have two important characteristics: First, they are recognized outside NASA as defining areas that require active programs to produce improvements in, or provide maintenance of, the quality of life both in the U.S. and abroad. Second, current analysis indicates that contributions to these objectives can be efficiently made by space activities. Although the division of goals and needs into 8 specific themes and 37 objectives is somewhat arbitrary, the Hearsh objectives** do form a meaningful set by which to categorize the contributions of candidate IUS experiments.
- (2) The analysis shall be restricted to consideration of those IUS experiments/instruments previously identified by Fairchild (see Appendix C of this report). These experiments/instruments are listed in four groups as shown in Table 1. The first group of 19 consists of sensing and transmission experiments/instruments required to demonstrate or develop the capability to perform the primary functions of their corresponding operational systems. The next group of eight forms a set of technology development experiments/instruments needed to produce an advanced payload support capability, particularly in the areas of station-keeping for synchronous orbits and power generation. These first 27 items were formally listed by Fairchild in Ref. 3. The remaining 6 experiments/instruments were not listed in that reference but have subsequently appeared in candidate IUS payloads described by Fairchild. The first five of these support the development of efficient, advanced communication systems. The last experiment/instrument shown in Table 1 is the 1.5-meter telescope radiometer, a highly important instrument for developing an advanced earth observation capability.

* These assumptions will be relaxed in Section C where the more general case is analyzed.

** Based on the relatively few objectives cited for basic science and communication R&D activities, these objectives appear to have been deemphasized.

Table 1

IUS EXPERIMENTS/INSTRUMENTS CATEGORIZED BY OBJECTIVE

NO.	FAIRCHILD EXPERIMENTS/INSTRUMENTS	GLOBAL CROP PRODUCTION	WATER AVAILABILITY	LAND USE AND ENVIRONMENTAL ASSESSMENT	LIVING MARINE RESOURCE ASSESSMENT	TIMBER INVENTORY	RANGELAND ASSESSMENT	LARGE SCALE WEATHER	WEATHER MODIFICATION	CLIMATE	STRATOSPHERIC CHANGES AND EFFECTS	WATER QUALITY	GLOBAL MARINE WEATHER
1	ORBITING STANDARDS PLATFORM												
2	MILLIMETER WAVE BROADBAND EXP.												
3	MILLIMETER WAVE SATELLITE-TO-SATELLITE EXP.											1	
4	HYDROMETER ATTENUATION DEPOLARIZATION EXP.	1	1					1					
5	RFI INVESTIGATION										2		
6	FIXED AND MOBILE SATELLITE COMMUNICATION		2								2	2	
7	ORBITAL ANTENNA RANGE												
8	RELAY STATION FOR DEEP SPACE PROBES												
9	ATMOSPHERIC X-RAY EMISSION DETECTOR	1	1				1	2	1	2	2		1
10	STEREO SEVERE STORM SENSING	2	2				1	3	3	2	1	1	3
11	MICROWAVE VERTICAL ATMOSPHERIC SOUNDER	2	1	2	2	2	2	3	3	3	1	1	3
12	MICROWAVE MEASUREMENT OF TEMPERATURE AND WATER VAPOR PROFILES	1	2	1	1	1	2	3	1	3	2	1	3
13	GEOSYNCHRONOUS CLOUD PHYSICS RADIOMETER	3	2		1		1	3	3	3	2	2	3
14	RADAR MEASUREMENT OF PRECIPITATION RATES OVER THE OCEAN		1		1			3	3	3	2	1	3
15	RADIO INTERFEROMETRY POSITION LOCATER												
16	CO ₂ LASER SYNCHRONOUS SATELLITE DATA RELAY RECEIVER EXP							1			1	1	
17	GEOSYNCHRONOUS LASER REFLECTOR												
18	PRECISION ATTITUDE DETERMINATION SYSTEM (PADS)												
19	PRECISE & ACCURATE TIME AND TIME INTERVAL EXP. (PATTI)												
20	FUEL CELL												
21	ECLECTIC SATELLITE PYROHELIONETER												
22	HIGH VOLTAGE SOLAR ARRAY SPACE PLASMA DRAINAGE EXP.												
23	MERCURY ION ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
24	LIQUID METAL SLIP RINGS								2				
25	CESIUM ION ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
26	TEFLON ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
27	COLLOID ION ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
28	DATA COLLECTION SYSTEM	1	1		1	1	1	2	2	2	2	2	2
29	MILLIMETER WAVE COMMUNICATION EXP.							1			1	1	1
30	ELECTROMAGNETIC ENVIRONMENT EXP.										2		
31	MULTIBEAM EXP.		2								2	2	
32	INTEGRATED COMMUNICATION EXP.	1	2	1	1	1	2	3	2	3	2	2	3
33	1.5-M TELESCOPE RADIOMETER	3	3	3	2	3	3	3	3	2	1	3	2

KEY: 3 = STRONG RELEVANCE

2 = MODERATE RELEVANCE

1 = PARTIAL RELEVANCE

BLANK = WEAK, NONE, OR UNKNOWN RELEVANCE



 = STRONG TO MODERATE RELEVANCE
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Table 1 (Continued)

No.	LOCAL WEATHER AND SEVERE STORM	TROPOSPHERIC POLLUTANTS	HAZARD WARNINGS	COMMUNICATIONS/NAVIGATION	SOLAR POWER	POWER RELAY	HAZARDOUS WASTE DISPOSAL	WORLD GEOLOGICAL ATLAS	DOMESTIC COMMUNICATIONS	INTERCONTINENTAL COMMUNICATIONS	BASIC PHYSICS AND CHEMISTRY	MATERIAL SCIENCE	COMMERCIAL INORGANIC PROCESSING	PRODUCTION/ISOLATION OF BIOLOGICALS	COMMERCIAL PROCESSING OF BIOLOGICALS	EFFECTS OF GRAVITY ON TERRESTRIAL LIFE	MAN LIVING AND WORKING IN SPACE	PHYSIOLOGY AND DISEASE PROCESSES	DISEASE CARRYING INSECTS	EARTH'S MAGNETIC FIELD	CRUSTAL DYNAMICS	OCEAN INTERIOR AND DYNAMICS	DYNAMICS AND ENERGETICS OF THE LOWER ATMOSPHERE	STRUCTURE, CHEMISTRY, DYNAMICS OF STRATOSPHERE/MESOSPHERE	IONOSPHERE - MAGNETOSPHERE COUPLING
1	1		1	3	1?	1?			3	3													1	1	
2	2		2	3	1?				3	3													2	2	
3	1		1	2					3	3									1				1	1	
4	1		1	2					2	2	1?												2	2	
5	2			3					3	3															
6	2	2		3					3	3															
7	1		1	3	1?	1?			3	3	1												1	1	
8																									
9	1			2	1	1			1	1										2			3		3
10	3		2	2	1	1			2	2															
11	3		1	1	1	1			1	1													1	1	2
12	3	1																					2	3	2
13	3	3	1	1																			2	3	3
14	2		1																				2	2	
15			1	3	1	1			1	1															
16	1		1	3					3	3													1	1	
17				3		1			3	3															
18				3	3	3																			
19				3					1	1	2														
20	2		2	2	2	2			2	2			2		2		2								
21			1	2					2	2													2	2	2
22				2					2	2			2		2		2								
23	2	2	2	2		2		2	2	2								2	2			2	2	2	
24				2					2	2			2		2		2								
25	2	2	2	2		2		2	2	2								2	2			2	2	2	
26	2	2	2	2		2		2	2	2								2	2			2	2	2	
27	2	2	2	2		2		2	2	2								2	2			2	2	2	
28	3	2	3	3					3	3									2						
29	2	2	3	3					3	3													2	2	
30	2			3					3	3													2	2	
31	2	2		3					3	3															
32	3	2	3	3					3	3									2			2	3	2	
33	3	1							1	1									3			2	2		

KEY: 3 = STRONG RELEVANCE
 2 = MODERATE RELEVANCE
 1 = PARTIAL RELEVANCE

BLANK = WEAK, NONE, OR UNKNOWN RELEVANCE

 = STRONG TO MODERATE RELEVANCE
 CITED FOR HEARTH SYSTEMS

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- (3) For the exemplar analysis described here, the benefit test (see item (2) of the previous section) is: to determine if the benefits of the operational system supported by the candidate experiment/instrument exceed the total life cycle costs of the operational system. If the answer is not known, the IUS candidate will be retained for further analysis but will be flagged as generating an unknown cost benefit.

Figure 1 shows schematically the steps required to apply the three criteria given previously in Section A. The major steps in this methodology are individually discussed and illustratively exercised in the following sections.

2. Relationship Between Experiments and Objectives: Analysis of Fairchild Experiments/Instruments

As shown in Fig. 1, the first step in the procedure to determine if a candidate IUS experiment/instrument can be justified is the assessment of whether the experiment contributes to an accepted objective (that is, to a Hearth Objective). For Fairchild Experiment/Instrument No. 6 (Fixed and Mobile Satellite Communication), the answer is clearly affirmative since this is essentially an early operational system supporting Hearth Objective 034, Communications and Navigation. For most of the other experiments, however, the answer is not obvious because these experiments are of an R&D nature and do not contribute as directly to the objectives. However, as stated in the discussion of this criterion, this relevance test is satisfied by such experiments if they contribute to the development cycle of operational systems that do make direct contributions to these objectives. SRI has subjected each of the 33 candidate IUS experiments/instruments defined by Fairchild to this relevance test and has identified the level of contribution potentially derivable from each experiment in each of the 37 Hearth objective areas. This exercise, was conducted by determining if the experiment/instrument either:

- (1) Provides an operational system capability contributing to a Hearth Objective, or
- (2) Comprises a developmental activity that, if successful, would provide an operational capability that could make a clearly identifiable contribution to a Hearth Objective.

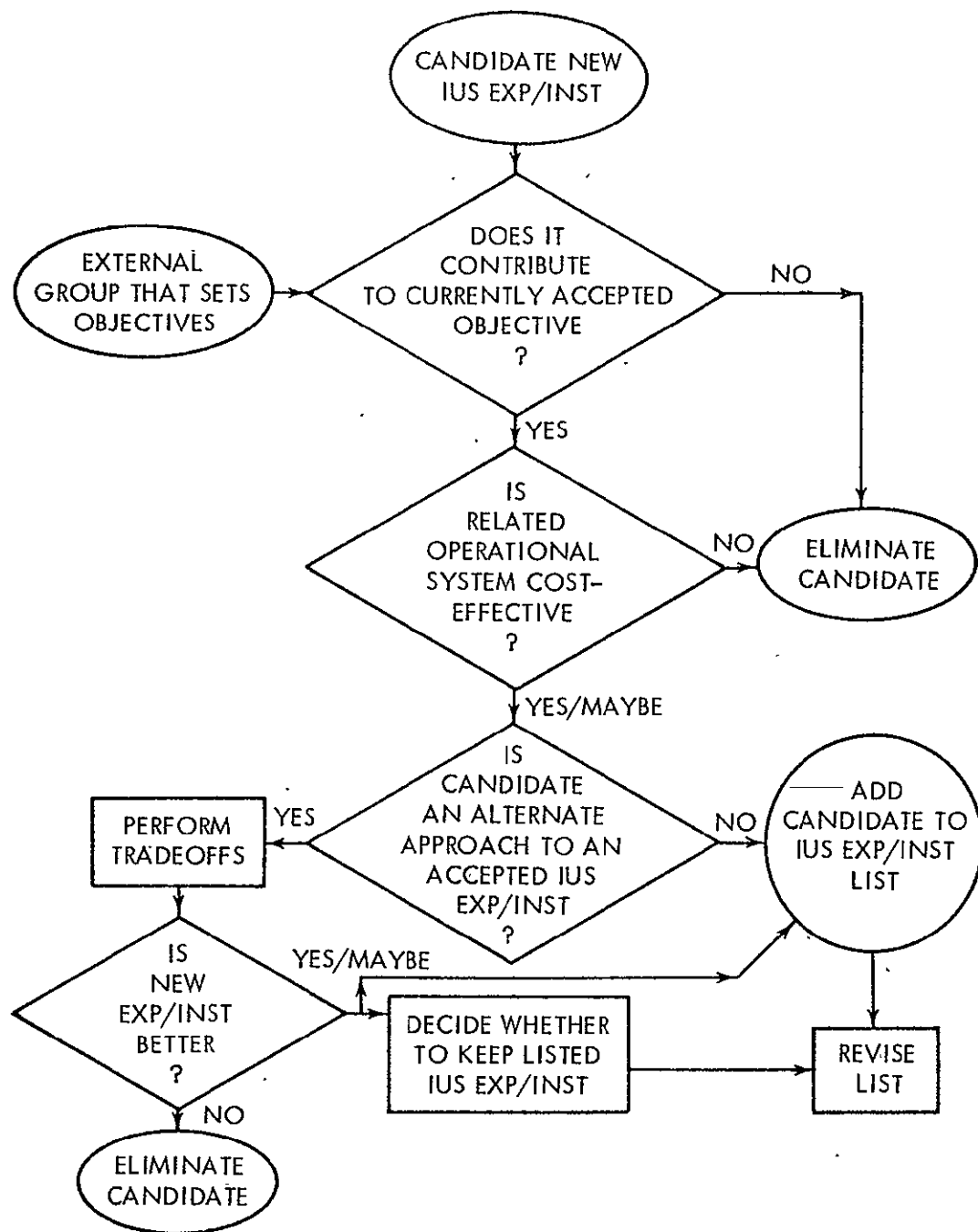


FIG. 1 METHODOLOGY FOR APPLYING JUSTIFICATION CRITERIA

This step was followed by an assessment of the criticality of each experiment in contributing to each of the Hearth Objectives. The results of this criticality analysis were expressed in terms of the relevance of each experiment to each objective using a four-level rating scheme. The rating scheme used is described below:

- (1) A rating of 3 was assigned to an experiment for its relevance to a given Hearth Objective if that experiment was judged critical to the operation or development of an operational system fielded to support the given Hearth Objective. For example, the 1.5 meter telescope radiometer experiment/instrument was given a rating of 3 for Hearth Objective 011, Global Crop Production, because an operational instrument with the resolution and multispectral capabilities of this candidate IUS instrument is required to realize the benefits possible in this application (objective) area.
- (2) A rating of 2 was assigned to an experiment for a given objective if it was felt that, although an operational system would be developed for this objective without flying the experiment in question, the performance level of the operational system would be markedly enhanced if the experiment were flown. For example, current station-keeping capabilities are probably sufficient to support operational systems capable of contributing to almost all of the Hearth Objectives. However, the development of ion engines to provide vastly improved station-keeping capabilities would markedly enhance the performance, for example, of advanced satellite communications systems by: (a) increasing the number of satellites that could be assigned a given frequency band (because they could be stationed at smaller nominal separations and still provide resolvable transmission sources) and (b) decreasing the costs of the ground-based antennas (because of a relaxation in the receiver and transmitter beam steering requirements).
- (3) A rating of 1 was assigned to an instrument for its relevance to a given objective if only a modest increase in the contribution to this objective could be identified from successful implementation of the experiment. For example, the condition of rangelands (Hearth Objective 016) is markedly dependent upon the amount of precipitation, some of which comes during severe storms; thus, a system that provides severe storm information is of some utility in determining the quality of these lands. However, since the primary method of using

multispectral scan data is sufficient to achieve this Hearth Objective and since the condition of rangelands is more affected by long-term weather and grazing history than by isolated severe storms, only a modest contribution to this objective accrues from the Stereo Severe Storm Sensor in the list of candidate IUS experiments.

- (4) A zero (or blank) rating was given in those cases where the relevance of an experiment to a given objective was either weak, nonexistent, or unknown; for example, no measurable degree of relevance could be assigned the Orbital Antenna Range in supporting Hearth Objective 015, Timber Inventory.

The results of the SRI analysis are shown in Table 1 where the above rating scheme was used to characterize the relevance of each experiment/instrument identified by Fairchild to the Hearth Objectives. As shown, every candidate experiment but one (No. 8, Relay Station for Deep Space Probes) is judged to have at least moderate relevance (a rating of 2) to at least one objective. Thus, only one of the experiments/instruments defined by Fairchild fails to satisfy the first justification criterion of contributing to an accepted objective.

The relevance ratings in Table 1 were determined by SRI without reference to a specific set of well-defined operational systems. Thus, the relevance ratings displayed might more appropriately be termed "conditional" relevance ratings in the sense that each rating reflects the level of contribution that each experiment/instrument could make to a given objective. However, in general, there are a number of possible operational systems that can be developed to support any one Hearth Objective and these systems may utilize quite different space-borne and ground-based elements. For example, an operational system to support Hearth Objective 041, Solar Power, might be structured as described in the Hearth Committee material (silicon devices used to convert solar energy to electrical energy, which in turn is used to generate microwave energy for transmission to earth-based collectors) or the system could use reflectors to concentrate solar energy to drive "conventional" thermal power plants in orbit, then convert the energy to microwaves for transmission to earth. In this example, it is obvious that, although there are certain R&D activities common to both approaches, there are unique requirements for each

operational system. Thus, although candidate IUS experiments that support either type of operational system are "conditionally" relevant, once a decision is made to deploy a given system, the experiments that do not support this system are no longer relevant.

The above observations imply that it will be necessary to define the operational systems supporting the Hearth Objectives before a reliable relevance rating can be derived. In addition, the cost-benefit analysis, which is needed to complete the second step of the experiment justification procedure (see Fig. 1), requires the definition of specific operational systems before the appropriate determination of life-cycle costs and derived benefits can be made.

The experiments/instruments identified by Fairchild did not have the associated operational systems defined. In addition, these experiments provide no support for five of the Hearth Objectives (see Table 1). Since the Hearth Committee material provided to SRI by GSFC did contain a description of a set of operational systems sufficient to support all Hearth Objectives, SRI attempted to utilize these operational systems in performing this analysis.

In order to retain the list of experiments compiled by Fairchild in the analysis, however, it would be necessary to identify those Fairchild-defined items which are needed to develop each Hearth-defined system. Table 2 shows the results of SRI's efforts to correlate the instruments identified by the Hearth Committee as requiring further development with those IUS candidate experiments identified by Fairchild. Because the Fairchild list does not contain all instruments which are deemed critical by the Hearth Committee, the IUS payloads derived from considering only the Fairchild-defined experiments will lack several potentially important experiments. Therefore, SRI needed to construct a set of instruments that would reflect the needs of the Hearth Committee's operational systems. The available data were not sufficient, however, to accomplish this task. The following problems were encountered.

- (1) The Hearth Committee material did not identify many of the supporting, non-critical experiments needed for successful implementation of the operational

Table 2
CORRELATION OF HEARTH AND FAIRCHILD INSTRUMENTS

HEARTH INSTRUMENTS	RELATED FAIRCHILD EXPERIMENTS/INSTRUMENTS
MULTISPECTRAL SCANNER	1.5-M TELESCOPE RADIOMETER
L & X BAND SENSORS	?
ACTIVE MICROWAVE SENSORS	MICROWAVE MEASUREMENT OF TEMPERATURE AND WATER VAPOR PROFILES MICROWAVE VERTICAL ATMOSPHERIC SOUNDER
SCANNING SPECTROMETER	—
RADAR ALTIMETER	—
MICROWAVE RADIOMETER	MICROWAVE MEASUREMENT OF TEMPERATURE AND WATER VAPOR PROFILES
SCATTEROMETER	RADAR MEASUREMENT OF PRECIPITATION RATES OVER OCEANS
IMAGING RADAR	—
VISIBLE & IR SPINSCAN RADIOMETER (VISSR)	GEOSYNCHRONOUS CLOUD PHYSICS RADIOMETER
ADVANCED SOUNDING & IMAGING RADIOMETER (AASIR)	GEOSYNCHRONOUS CLOUD PHYSICS RADIOMETER
PASSIVE IR RADIOMETER	GEOSYNCHRONOUS CLOUD PHYSICS RADIOMETER
LASER ABSORPTION SPECTROMETER	—
LACTATE	—
COMMUNICATIONS BEACONS	ORBITING STANDARDS PLATFORM (?) MULTIBEAM EXPERIMENT
HIGH FREQUENCY TRANSPONDERS	MULTIBEAM EXPERIMENT MILLIMETER WAVE COMMUNICATIONS EXP. MILLIMETER WAVE BROADBAND EXP.
ACTIVE IR SENSORS	?
IMAGING DEVICE	STEREOGRAPHIC SEVERE STORM SENSING
RELAY SATELLITE	MILLIMETER WAVE SATELLITE-TO-SATELLITE EXPERIMENT CO2 LASER SYNCHRONOUS SATELLITE DATA RELAY RECEIVER EXP. DATA COLLECTION SYSTEM

KEY: ? Probable, but unclear correlation
— No apparent correlation

systems. Therefore, use of this material alone would not suffice to define the complete set of candidate experiments which should be analyzed.

- (2) A list consisting of all the experiments explicitly identified by Hearth and Fairchild would probably constitute a complete, but somewhat redundant, list of candidate experiments. Any overlap of instruments would have to be removed before this approach would yield a meaningful set of candidates; but the correlation of instruments, as displayed in Table 2 is not sufficiently precise to do this.

In view of the lack of a completely consistent set of operational systems and the related experiments/instruments needed for development of these systems, SRI decided to select IUS payloads using the following approach:

- (1) The Fairchild list of instruments will be used whenever a specific list of instruments is needed in the analysis as, for example, in formally selecting specific instruments to make up an IUS payload.
- (2) The Hearth set of operational systems will be used in assessing the benefits and life-cycle system costs required to achieve these benefits (Criterion No. 2 on page 5 and the second test shown in Fig. 1).
- (3) The correlation shown in Table 2 has been used to identify the relevant use of Fairchild instruments in the Hearth operational systems. The cross-hatched boxes in Table 1 display the derived moderate to high relevance areas. Arbitrarily re-assigning a relevance rating of 3 to these entries produces the set of relevance ratings that SRI will use in this study. This overstates the relevance assigned to any given experiment but the available data do not permit the construction of a more meaningful set of relevance ratings for the Fairchild experiments.

This approach assures complete, although not fully consistent, data that permit illustrative application of each step of the analysis developed by SRI in this study. However, this lack of fully consistent sets of data implies that the primary value of the example cases contained in this report is to provide visibility to the techniques involved rather than yielding a fully justified set of IUS payloads.

Based on the above observations, the authors have identified the following appropriate steps that should be taken to produce valid and useful results (including a relevance table similar to Table 1) with this methodology:

- (1) First, a set of accepted objectives should be determined. (The Hearth Committee has performed the initial exercise in this area, as further discussed in Section C.)
- (2) Second, the operational systems that efficiently meet these objectives should be defined. The Hearth Committee has also identified such a set of systems, but further work is needed to ensure that these systems are the best ones to achieve the stated goals. These systems should be characterized in sufficient detail to carry out the third step below.
- (3) Third, the analyst should determine what developmental activities are needed to assure implementation and fielding of the desired systems. The candidate IUS experiments/instruments then consist of those R&D experiments and early operational systems consistent with this determination.

The procedures in steps 2 and 3 can be reiterated to refine the selection of the operational systems desired. This procedure implies an important philosophical departure from past NASA activities: NASA programs would be designed almost completely to stress what should be done to support national goals rather than identifying what can be done after a program has been defined. As such, the procedure is fully consistent with the philosophy of NASA's "Outlook for Space" study conducted by the Hearth Committee. This approach eliminates planning research programs for which the analysis indicates no meaningful application.

3. Benefit Sufficiency Determination: Analysis for Selected Hearth Systems

a. Introduction

The second major step in the experiment justification procedure (see Fig. 1) is to determine the sufficiency of the benefits attributable to each candidate IUS experiment/instrument. The sufficiency test defined for this analysis is to determine if the benefits accruing from the related operational system exceed the system costs. In this section, we will

discuss the criteria to be used in determining these benefits and costs and will illustrate the application of these criteria by performing a cost-benefit analysis for selected operational systems defined in the Hearth Committee material.

b. Determination of Costs

Section V and Appendix D of this report contain discussions of the various user-charge strategies that could be used to determine the charges to be assessed against sponsors for IUS experiments. Some of the results of those discussions are applied in this section, where the costs to be included in determining the system costs are identified.

Those costs directly attributable to the development, launch, and operation of an operational system form the minimum set of costs chargeable to that system. These costs include:

- (1) Payload R&D costs
- (2) Payload procurement costs
- (3) Direct operating costs for launch vehicle and launch support (including Tug, IUS, or Spacelab, if appropriate)
- (4) R&D, hardware procurement, and operating costs for ground based elements of the system (including R&D costs for developing analytical techniques)

The sum of these costs is obtainable from the Hearth Committee material for each of the Hearth systems defined to support the Hearth Objectives. They form a good basis for assigning costs to each of the Hearth operational systems. There are, however, two other major cost items that could be added to these to determine the total costs associated with an operational system. These are:

- (5) Vehicle (Shuttle, IUS, etc.) procurement costs, and
- (6) Vehicle R&D costs.

As pointed out in Section V, for the anticipated usage level of the Shuttle, a requirement to recover vehicle hardware procurement costs would increase only modestly the cost for an individual launch.

SRI has estimated that a requirement to recover such costs would increase the chargeable system costs for any Hearth system by probably less than 5% of the costs associated with the first four cost items. The inherent uncertainties in the level of benefits to which the system costs are to be compared in the cost-benefit analysis are greater than this. Thus, inclusion of vehicle procurement costs is not expected to affect a system's justification on the basis of cost-benefits. Therefore, in this study we have ignored such costs, although their inclusion may be warranted in formal application of the methodology.

The recovery of vehicle R&D costs, as discussed in Section V, is probably not required under the current circumstances where the development of these systems has been approved by Congress and the Office of Management and Budget (OMB). Should these programs come under fire, however, it is not unlikely that the R&D costs would have to be recovered. Such a development would markedly increase the costs chargeable to each operational system. The set of justifiable experiments would be correspondingly reduced because fewer operational systems could be justified on a cost-benefit basis. SRI has assumed that these vehicle R&D costs do not need to be recovered and that the system costs given in the Hearth Committee material reflect valid system costs for use in the cost-benefit analysis. This assumption is consistent with the existing program approval by OMB and Congress.

c. Determination of Benefits

In the course of this study, SRI has examined and evaluated a large number of economic benefit analyses previously performed for space-based systems.⁴⁻⁸ NASA contractors have identified the types of benefits attributable to space systems, the beneficiaries of these benefits, and (although somewhat less explicitly) the potential users of the services. There are, however, wide differences in the quantitative level of benefits assigned in these studies for a given operational system. Therefore, it is necessary to establish a set of criteria for specifying the appropriate set of economic benefits for justifying a candidate IUS experiment on the basis of cost and benefits.

Before defining these criteria, however, it is necessary to identify the basic sources of the differences in the results of different benefit analyses for a given system. These differences are primarily due to two things: first, differences in the benefits assigned to a given level of utilization of the services provided by the system; and second, differences in the expected level of utilization. In response to the need to identify a meaningful set of benefits for use in the cost-benefit tradeoff, SRI divided the benefits attributable to an operational system into two classes.

The first class consists of those hard, demonstrable benefits derived from conservative estimates of utilization and the associated benefits. Benefits to be included in this class are those that accrue to existing organizations or user groups already operating under procedures that utilize the type of information or service provided by the operational system being considered, assuming conservative estimates of the future usage level of the service or information by these groups. The only additional benefits that should be included in this class of hard, demonstrable benefits are those that arise from any other firmly planned utilization of the new service; for example, by organizations that have no past history of utilizing such information or service but have committed themselves to future utilization. A specific example of this situation may be forthcoming if the United States Postal Service (USPS) decides to implement an electronic mail system or if Federal regulations, for example, were to require all vessels registered in the U.S. to carry a beacon for relaying distress calls to a satellite system.

The second class of benefits contains the remaining benefits identified in the benefits analysis. SRI calls such benefits potential benefits.* These benefits are those benefits other than hard, demonstrable benefits that could accrue, for example, under the following conditions:

* Note that some investigators characterize all identifiable benefits as potential benefits (see, for example, page 1-7 of the Final Report of Reference 6) and divide these into "hard" and "soft" benefits. SRI prefers the terminology of this study, using the term "total" benefits to represent the sum of "potential" and "hard, demonstrable" benefits.

- (1) Basic operating procedures of user groups are modified to make expanded use of the information or service available from the operational system. (Such action usually calls for an investment of funds or manpower on the part of users that cannot be guaranteed by NASA. Thus, any related benefits are truly "potential" in nature.)
- (2) The demand for the service by users identified in the hard, demonstrable benefits analysis exceeds the conservative estimates used in estimating such benefits. (The additional benefits would be termed potential.)

In the methodology, to determine if candidate IUS experiments can be justified, SRI asserts that the only experiments which should be unconditionally justified are those for which the related operational systems have hard, demonstrable benefits exceeding the life cycle costs of the systems. SRI further asserts that, in the absence of non-economic benefits which would dictate otherwise (see Section C), an experiment should be removed from further consideration for IUS flights if the sum of the potential and hard, demonstrable benefits is less than the life cycle costs of the related operational system.

However, there is an intermediate case not covered in the previous paragraph: when the life cycle costs are greater than the hard, demonstrable benefits, but less than the total benefits identified. For such cases, SRI recommends that the subject experiments be retained for possible inclusion on IUS payloads but that they be tagged as conditionally justified. This status of conditional justification will be utilized in the importance ranking of experiments, discussed in Section III.

Before proceeding to a set of illustrative benefit analyses in the following section, there are two important points that should be made. Unless recognized, they can create problems in determining a meaningful set of benefits attributable to a candidate experiment. The first is that the benefits accruing from an operational system will not be fully realized at deployment of the system: There will be a gradual, rather than instantaneous, realization of the benefits. This is true, even for the hard, demonstrable benefits, although the time constant associated with these benefits is generally shorter than for the potential benefits.

This fact should be factored into the assessment of benefits coming from an operational system. The second point is that the benefits being addressed in this study are really incremental benefits, not gross benefits. For example, in determining the benefits from improved crop forecasting, the appropriate benefits are those that accrue because of the reduction in prediction errors relative to existing prediction errors, supplemented by those benefits that result from cost savings for producing the current forecasts: the benefits are not the benefits resulting from providing crop forecasts where none existed before. Fortunately, most benefit analyses that have been made have included this consideration.

This observation also has relevance to those cases where several individual operational systems may be required to support a given objective. For these cases, it will be necessary to determine what fraction of the benefits are attributable to each system in order to avoid counting benefits twice in justifying candidate IUS experiments. An example of such a situation is given in the following section where two separate operational systems are combined to define the overall system for providing agricultural benefits.

d. Analysis for Selected Hearth Systems

Among the candidate missions for the STS, there has been considerable attention paid to orbiting operational systems that can provide direct support in the areas of agriculture, communications, severe storm sensing, and water availability. Recently, the energy shortage has enhanced interest in space-based systems to help satisfy our national energy needs. As a result, systems contributing to Hearth Objective 041, Solar Power, are being subjected to new, critical cost analyses. Because of the widespread interest in these application areas, SRI has selected four operational systems that contribute to these five areas to illustrate the application of the criteria identified above for assessing the sufficiency of benefits. Each system was subjected to a cost-benefit analysis utilizing readily available data on both system costs and benefits for these systems.

1) Communications

The operational system defined for Objective 051, Domestic Communications, was selected for analysis in this applications area. The overall system consists of an R&D activity between 1980 and 1985 to develop the technology for assembling and deploying large antennas and high power transmitters. These developments are to be utilized, starting in 1985, to implement a network of 20 orbiting satellites (plus 4 spares) by the year 2000. The satellites will weigh 1200 lb and contain 15 transponders with a frequency of 12 to 15 GHz and 15 transponders operating in the 4 to 6 GHz frequency range. This system is to be improved later to accommodate even higher frequencies. The system costs from 1980 through the year 2000 are estimated at \$1.415 billion.

A large number of studies have been performed to analyze the cost benefits of satellite communication networks (for example, Reference 8). These analyses predict that satellite networks are competitive with land line systems, particularly for distances exceeding 200 miles. Recent experience with domestic communication satellites confirms this prediction. This experience and the related analyses indicate that for communications between points more than 200 miles apart, a satellite system is the most cost-effective approach to meet the need. For the purposes of this study, therefore, the benefit sufficiency test for the proposed communications system reduces to determining if a conservative prediction of the demand for future long-range communications is consistent with the number of satellites proposed. The Hearsh Committee independently reached the same conclusion.

Analysis of such communication demand presents a somewhat uncertain situation. Historical growth trends indicate a growth rate of 10 to 15% a year for such services. Initial growth rates of approximately 20% were experienced by COMSAT. These two facts presage a traffic demand capable of supporting the large systems proposed by the Hearsh Committee. However, this year COMSAT's growth has slowed to 10%, and the upsurge in the usage of long-range communications that some predicted in response to increased personal travel costs has not occurred. In addition, one major potential user of the system, the USPS, has not yet committed itself to

implementing a large electronic mail system. Thus, the demand for the long-range communication services does not yet appear to be sufficient to support the proposed system on the basis of hard, demonstrable benefits. Because of the potential benefits, however, the system may be conditionally justified on the basis of cost and benefits.

2) Energy

The system defined by the Hearth Committee to support Objective 041, Solar Power, is composed of a large solar cell array, a microwave generation system, a space radiating antenna, a ground receiving antenna, and a ground-based microwave conversion system. The key R&D issues involve techniques for handling large space systems (7 to 11×10^6 kilograms), a low-cost transportation system, and low-cost power sources. Although not explicitly stated by the Hearth Committee, another key issue is the demonstration of high pointing accuracy for systems of this size. Costs of between \$22 and \$65 billion are estimated for the prototype system with the cost for each additional unit estimated at between \$7.5 and \$29.5 billion.

The market value of the electric power from one such power station will be approximately \$1 billion a year (assuming that electricity will sell for around 2¢ per kilowatt hour). This figure will, of course, increase markedly if the price increases of the past two years for fossil fuels and uranium continue for any length of time. There are, of course, additional benefits to be gained from the use of solar power stations. These economic benefits accrue from saving our limited fossil fuel resources and the reduction of environmental pollution from power generating sources. Currently, it appears that these benefits must be included to merit consideration of space solar power stations on a cost-benefit basis. The required benefit analysis is currently being conducted by various NASA contractors and should be available within the next year. Of primary interest in the ongoing analysis is the tradeoff between earth-based and space-based systems.

On the basis of the above observations, the solar power system suggested by the Hearth Committee must currently be viewed as questionably justified on a cost-benefit basis. Therefore, the experiments

associated with this system cannot be currently justified on the basis of benefits provided by this operational system.

3) Agriculture and Water Availability

It has been recognized that improved crop forecasting data can be gathered from space.⁴⁻⁷ The Hearsh Committee has defined a system that can provide such a service. The proposed system supports both Objective 011, Global Crop Production, and Objective 012, Water Availability. The initial system consists of the Earth Observation Satellite (EOS) system which will provide wheat forecast data. This system is to be replaced with an advanced system in 1990 to provide data on all crops. The system would be improved in the year 2000 by the addition of an all-weather capability. These systems are to be supplemented, starting in 1990, by the microwave sensors fielded primarily to support Hearsh Objective 012, Water Availability. The system costs for the basic crop forecasting system are estimated to be \$2.3 billion between the start of the program in 1977 and the implementation of the first all-weather system in the year 2000. An additional \$1.0 billion is needed to field the microwave system associated with Hearsh Objective 012.

The benefits from improved crop forecasting accuracy have been assessed in several studies.⁴⁻⁷ SRI has analyzed these studies and has found: (1) all classes of appreciable benefits have been identified and (2) there are wide differences in the levels of benefit estimated by the various investigators. SRI has identified the sources of these differences. For example, the differences between the benefits estimated in Refs. 4 and 5 to result from improved wheat crop forecasting are due to: the use of different demand elasticities (0.1 in Ref. 5 and nominally 0.065 in Ref. 4), inclusion of the effects of government policy (in Ref. 5) to produce departures from a freely competitive market, differences in the assumed market value of the wheat crop, and differences in the reduction in forecast errors assigned to the operational space-based system.

SRI has taken the results of the four benefit analyses evaluated⁴⁻⁷ and has identified the following set of benefits for use in the cost-benefit analysis step of the methodology for justifying IUS experiments:

- (1) It is estimated that hard, demonstrable benefits of at least \$10 million per year will result from the wheat-only system. These benefits are estimated to be at least \$40 million per year when other crops are included. These are essentially the results of Ref. 5 where slight modifications to crop values have been made to reflect recent prices for important cash crops.
- (2) The potential benefits [total benefits less those in (1) above] are estimated to be approximately \$30 million per year for the wheat-only system. These benefits grow to between \$150 million and \$225 million for the initial all-crop system and grow to between \$225 million and \$375 million by the year 2000 when agromet models and an all-weather capability are fully utilized. The range in values for the all-crop system is due to the uncertainties that now exist in the benefits that can be obtained from improved forecasts for soybeans.* Otherwise, the numbers are essentially the total benefits of Ref. 4 decreased by: the hard, demonstrable benefits in (1) above; and those benefits termed "soft" (potential) in Part I** of Reference 4.

A comparison of these benefits with the related system costs shows that the cost benefits clearly justify the total system if potential benefits are included. However, the hard, demonstrable benefits are not sufficient to do so.

This example provides an illustration of a situation in which different systems (those proposed by the Hearth Committee separately for Objectives 011 and 012) are used to provide benefits in a single applications (objective) area. As previously stated, however, the justification of a combined set of two systems does not necessarily justify both systems: one must demonstrate that the increase in capability afforded by an individual system is justified on a cost-benefit basis. In this case, this condition implies that, although, the two given systems can be justified as a unit, we must further identify the benefits attributable to each individually and assess their individual cost benefits.

* Reference 4 assigns a large value to such benefits while Ref. 5 indicates that the resilience of soybeans to adverse growing conditions makes the utility of space-based data of questionable value for this crop. This problem needs to be addressed in future studies.

** Pages 1-8 and 1-9.

For the crop forecasting case analyzed here, all the benefits identified above are attributable to the system proposed by the Hearth Committee except for those that accrue from implementation of an agromet yield model. The benefits from this model are all potential benefits and are assessed to rise from near zero in 1990 to between \$75 and \$150 million by the year 2000 (depending on the benefits which can be realized by applying the model to the soybean crop). Subtracting these benefits from those identified above for the complete two-component system, we conclude that the Hearth Committee system proposed specifically for crop forecasting is conditionally justified as was the combined system. The potential benefits in crop forecasting attributable to the microwave system designed primarily to support Objective 012, Water Availability, may or may not be sufficient to justify this system. However, a quick analysis of the benefits attributable to this system in supporting its primary objective of Water Availability indicates that additional potential benefits are assignable to this system to merit its justification on the basis of cost benefits: annual benefits of \$50 to \$150 million are achievable in supporting the Water Availability objective. Few of these, however, can be termed hard, demonstrable benefits.

4) Local Weather and Severe Storms

The system proposed by the Hearth Committee to support Objective 031 (Local Weather and Severe Storms) was also analyzed by SRI to assess the justification of IUS instruments that support the development of this operational system. The system consists of satellites in geosynchronous orbit. The system costs have been identified by the Hearth Committee as being \$2.48 billion for this system in which an early sensing capability like that of the Storm Satellite (STORMSAT) is provided by 1985, followed by implementation of operational systems based on the Synchronous Earth Observation Satellite (SEOS) concept in 1993.

The benefits from severe storm sensors have been previously analyzed.⁶ Considering the time required after implementation to realize the achievable benefits, discounting benefits to the airline industry (since

many people feel this industry benefits only a small number of people and creates disbenefits outweighing the benefits), and applying conservative estimates of expected usage of the service by potential users, the average annual level of hard, demonstrable benefits is estimated to be approximately \$120 million between 1985 and 1993 and \$250 million between 1993 and the year 2000. The system costs are less than these hard, demonstrable benefits. The IUS instruments that support the development of this geosynchronous system are, therefore, justifiable on a cost-benefit basis even without having to consider the benefits attributable to the system because of its contribution to other objectives, such as large scale weather forecasting (Objective 021).

5) Utility of Results

The above results indicate that several, if not most, of the operational systems proposed by the Hearth Committee can be shown to be cost-effective, at least on the basis of potential benefits, in contributing to the Hearth Objectives. SRI has formally demonstrated that candidate IUS instruments that support the development of four of these systems can be at least conditionally justified. However, the lack of a strong correlation between the list of experiments proposed by Fairchild and the set of instruments required to develop the systems proposed by the Hearth Committee indicates that further analysis is needed before specific Fairchild instruments can be termed justified. Undoubtedly, many of these instruments are justifiable, but the primary value of the preceding cost-benefit discussion is to provide visibility to the definition and application of the appropriate criteria.

4. Tradeoff Analysis

Ordinarily, if a candidate experiment has been shown to be both relevant and to produce sufficient benefits, it can be considered justified for possible inclusion in an IUS payload. However, there are cases where the experiment represents an alternate technical approach to performing the same or equivalent function of another, previously justified IUS experiment or by an effort outside the IUS program. There are, of

course, cases where both of such alternative approaches should be considered as providing valid candidates for NASA payloads. However, in order to ensure that similar experiments are not needlessly retained on the list of justified IUS experiments, SRI has introduced a tradeoff analysis in the justification process to eliminate those alternatives that are clearly less desirable (see Fig. 1).

The tradeoff analysis to determine the "best" among alternative approaches is restricted in this discussion to a comparison among competing candidates in the Fairchild list and to a determination of whether the experiment is scheduled for flight on a system other than IUS.

The list of Fairchild instruments has three sets of competing experiments. The first includes the Orbital Antenna Range and the Orbiting Standards Platform; the second set consists of the four ion engines for developing an advanced station-keeping capability; the third consists of the EM Experiment and the RFI Investigation. The decision to keep or eliminate these various experiments was made as follows:

- (1) The Mercury Ion Engine is being flown on non-IUS missions. Thus, it can probably be dropped from the list of justified IUS experiments.
- (2) Currently, there is no valid technological basis to merit choosing one of the remaining three engines (items 25, 26, and 27 in Table 1) over the others. Therefore all three should be retained.
- (3) The Orbital Antenna Range and the Orbiting Standards Platform experiments perform several of the same functions. Both are retained, however, to assure inclusion of their unique capabilities.
- (4) The RFI Investigations and EM Experiment appear to be identical. Thus apparently only one of these should be retained.

It should be noted that for the cases treated here, the tradeoff analysis appears to be independent of the particular set of operational systems assumed. The generalized tradeoff analysis discussed in Section C, however, shows that even this analysis may have to include

consideration of the operational systems supported by the R&D experiments being analyzed.

5. Identification of Potential Sponsors

The justification of IUS experiments/instruments has been undertaken to isolate those experiments that have identifiable benefits in support of objectives of recognized and generally accepted value. Such experiments are precisely those for which it should be easiest to enlist the support of agencies outside NASA in providing funding assistance. This assistance is needed to maximize the use of the IUS program by extending it beyond the limits imposed by a fixed level of NASA funding. It also serves as visible endorsement of the program, thereby enhancing the recruitment of sponsors for subsequent STS flights. In order to realize these potential benefits, however, it is necessary to identify the potential sponsors for the justified IUS experiments. This section discusses how potential sponsors can be identified.

There are two major groups from which potential sponsors for a given experiment might realistically be expected to emerge: (1) the beneficiaries of the services provided by the related operational systems, and (2) the users of these services.

The scope and magnitude of this study does not permit the identification of the specific corporate firm or government office that qualifies as a user, beneficiary, or sponsor of each candidate IUS experiment. However, SRI has defined eight general classes of users, sponsors, and beneficiaries for the Fairchild experiments/instruments used in this study to demonstrate the method. The eight classes are listed, and example members of each class are given below:

- (1) Federal Government: NASA, Federal Communications Commission (FCC), Department of Transportation (DOT), Department of the Interior (DOI), Department of Defense (DoD), Environmental Protection Agency (EPA), USPS, United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA).
- (2) Non-Profit/Special Interest: American Gas Assoc. (AGA), American Medical Assoc. (AMA), The Grange, SRI, Ford Foundation.

- (3) Local/State Governments: transportation departments, health departments, law enforcement agencies.
- (4) Domestic Commercial: General Motors (GM), Columbia Broadcasting System (CBS), COMSAT, Humble Oil.
- (5) Foreign Commercial: Krupp, Fiat, British Petroleum (BP), MATRA
- (6) Other Foreign/Multinational: Saudi Arabia, Organization of Petroleum Exporting Countries (OPEC), United Nations (UN), North Atlantic Treaty Organization (NATO), European Space Agency (ESA)
- (7) Educational: state university systems, National Science Foundation (NSF)
- (8) General Public.

These eight classes were used to categorize the primary (i.e., direct) beneficiaries of the services provided by operational systems for which the Fairchild experiments form part of the required R&D activity. The results of that exercise are shown in Table 3. It should be recognized that the general public (Class No. 8 above) is actually an ultimate beneficiary in essentially all cases. Therefore, we have restricted the entries for Class No. 8 in Table 3 to those cases where the general public is a direct beneficiary (for example, Experiment 22 supports the development of high-power broadcasts from satellites directly to home receivers).

The classes of potential users of the services to be provided by the related operational systems are also displayed in Table 3 for the 33 instruments identified by Fairchild. Users refer to those who would employ the relevant operational systems in the performance of their day-to-day operations. Note that not every beneficiary is a user. For example, although the general public is a direct beneficiary for many experiments, it is a direct user for only a few of the related operational systems.

We propose that only those groups that are both users and beneficiaries of a particular experiment are appropriate for NASA to approach in enlisting financial assistance in flying that experiment. For this reason it was necessary to identify both users and beneficiaries. The results of the analysis, however, show that this set of potentially

Table 3
CATEGORIZATION OF IUS EXPERIMENTS/INSTRUMENTS
BY BENEFICIARY, USER, AND SPONSOR

NO.	FAIRCHILD EXPERIMENTS/INSTRUMENTS	PRIMARY BENEFICIARIES	POTENTIAL USERS	POSSIBLE SPONSORS
1	ORBITING STANDARDS PLATFORM	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1
2	MILLIMETER WAVE BROADBAND EXPFRIMENT	1,2,3,4,5,6,8	1,2,3,4,5,6	1
3	MILLIMETER WAVE SATELLITE-TO-SATELLITE EXPERIMENT	1,4,5,6	1,4,5,6	1
4	HYDROMETER ATTENUATION/DEPOLARIZATION EXPERIMENT	1,4,5,6	1,4,5,6	1
5	RFI INVESTIGATION	1,4,5,6	1,4,5,6	1
6	FIXED AND MOBILE SATELLITE COMMUNICATION	1,2,3,4,5,6,8	1,2,3,4,5,6,8	1,4,5,6
7	ORBITAL ANTENNA RANGE	1,2,3,4,5,6,8	1,2,3,4,5,6,8	1
8	RELAY STATION FOR DEEP SPACE PROBES	1,7	1,7	1
9	ATMOSPHERIC X-RAY EMISSION DETECTOR	1,4,5,6,8	1,4,5,6	1
10	STEREO SEVERE STORM SENSING	1,2,3,4,5,6,8	1,3,4,5,6	1
11	MICROWAVE VERTICAL ATMOSPHERIC SOUNDER	1,4,5,6	1,4,5,6	1
12	MICROWAVE MEASUREMENT OF TEMPERATURE AND WATER VAPOR PROFILES	1,2,4,5,6	1,4,5,6	1
13	GEOSYNCHRONOUS CLOUD PHYSICS RADIOMETER	1,2,4,5,8	1,2,4,5	1
14	RADAR MEASUREMENT OF PRECIPITATION RATES OVER THE OCEAN	1,4,5,6	1,4,5,6	1
15	RADIO INTERFEROMETRY POSITION LOCATER	1,2,3,4,5,6,8	1,2,3,4,5,6	1
16	CO ₂ LASER SYNCHRONOUS SATELLITE DATA RELAY RECEIVER EXPERIMENT	1,4,5,6	1,4,5,6	1
17	GEOSYNCHRONOUS LASER REFLECTOR	1,4,5,6,7	1,4,5,6,7	1
18	PRECISION ATTITUDE DETERMINATION SYSTEM (PADS)	1,7	1,7	1
19	PRECISE AND ACCURATE TIME AND TIME INTERVAL EXPERIMENT (PATTI)	1,2,6,7	1,2,6,7	1
20	FUEL CELL	1,2,4,5,6	1,2,4,5,6	1
21	ECLECTIC SATELLITE PYROHELIO METER	1,7	1,7	1
22	HIGH VOLTAGE SOLAR ARRAY SPACE PLASMA DRAINAGE EXP.	1,2,4,5,6,7,8	1,2,4,5,6,7	1
23	MERCURY ION ENGINE	1,2,4,5,6	1,2,4,5,6	1
24	LIQUID METAL SLIP RINGS	1,2,4,5,6,7,8	1,2,4,5,6,7	1
25	CESIUM ION ENGINE	1,2,4,5,6	1,2,4,5,6	1
26	TEFLON ENGINE	1,2,4,5,6	1,2,4,5,6	1
27	COLLOID ION ENGINE	1,2,4,5,6	1,2,4,5,6	1
28	DATA COLLECTION SYSTEM	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	1
29	MILLIMETER WAVE COMMUNICATION EXP.	1,2,3,4,5,6,8	1,2,3,4,5,8	1
30	EM ENVIRONMENT EXPERIMENT	1,4,5,6,7	1,4,5,6,7	1
31	MULTIBEAM EXPERIMENT	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6
32	INTEGRATED COMMUNICATION EXPERIMENT	1,2,3,4,5,6,7	1,2,3,4,5,6,7	1
33	1.5-M TELESCOPE RADIOMETER	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	1

KEY: 1 = Federal Government
2 = State/Local Government
3 = Non-Profit/Special Interest
4 = Domestic Commercial
5 = Foreign Commercial
6 = Other Foreign/Multinational
7 = Educational
8 = General Public (Directly)

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promising sponsors is the same as the list of users since every user is also a beneficiary.

SRI has evaluated the likelihood of obtaining formal sponsorship from the users shown in Table 3. The results of that exercise are shown in the far right-hand column of Table 3. It appears that the Federal Government is the only sponsor that can reasonably be expected to provide funds for most of these IUS experiments. However, the reasons for eliminating most of the potential sponsors (i.e., the users listed in Table 3) have been derived from years of personal experience on the part of the study team members and were independently verified by SRI in another study.¹ The list of promising sponsors was restricted to those shown in Table 3 for the following reasons:

- (1) The funds available for R&D in most user agencies are limited: most of the budget is for operational purposes. Thus, although funds might be available for utilizing an operational system, the limited funds traditionally spent on R&D activities make the support of the (primarily) R&D IUS experiments unlikely, unless special inducements are offered, such as a reduction in the user charges for the operational system (see Section V). However, note that where an IUS experiment/instrument offers the equivalent of an operational service (as for Experiment No. 6 and, to a certain extent, No. 31), SRI feels that a higher probability exists in enlisting sponsors because their operational funds would be used in those cases.
- (2) The mere act of asking a potential user to sponsor an IUS flight is likely to have an unfavorable influence on his decision to use the service because NASA may be discussing the cost of the service before the user can fully recognize its benefits. This problem is minimized if the time interval between his expenditures and the realization of his benefits is short.
- (3) If the general public is the ultimate beneficiary, then many people feel that the Federal Government should take the responsibility for supporting the R&D phase even though non-governmental agencies may use the operational system. Since the justifiable experiments support at least one Hearth Objective and since these objectives are essentially based on applications that benefit society as a whole, SRI believes that the initial impulse of potential sponsors will be to say "Let Uncle Sam do it." There are many

precedents which can lead potential sponsors to conclude that the Federal Government will do it.

Through assessing the impact of different user charge strategies on potential sponsors (see Section V), SRI has also concluded that successful development of sponsors will take more than merely pointing out to them the benefits that might accrue if a given operational system were implemented. Such development will require long-term interactions between NASA and these potential sponsors. In fact, as pointed out in Reference 1, the interaction with the potential user or sponsor of any NASA capability is probably the most critical operation in developing the user community. The justification of experiments, the identification of potential sponsors, and the determination of viable funding strategies (the essential elements of this study), to some extent, are supporting operations for the user interaction operation, which is the crucial step in making these supporting operations worthwhile.

C. GENERALIZED ANALYSIS

In the previous section, the generality of the results and the methodology is restricted by two conditions:

- (1) The Hearsh Committee objectives identified in Appendix B were assumed to be the only acceptable objectives.
- (2) Any IUS experiment had to pass the cost-benefit test in order to be justified.

Neither of these conditions need be observed for every case, however, as illustrated by the fact that existing, justified government-supported programs in basic science satisfy neither of these two conditions and, yet, we expect such work to continue at some substantial level of support. Thus, it is desired to remove the constraints on the methodology imposed by these two conditions. The removal must be done in such a way, however, that the methodology still filters out unjustifiable experiments.

The first step in achieving the desired generalization is to expand the set of Hearsh Objectives identified in Appendix B to include

consideration of goals and needs which lie outside the application areas.* The second step would be to include a function in the methodology that would continually monitor the attitudes outside NASA to determine the currently valid objectives and the grounds for program justification and to make these known within NASA. In this way, the methodology developed in this and other studies¹ can be assured of using all available grounds for program justification without utilizing those that are no longer, or never were, in favor. This monitoring activity should be a continuing one, because the accepted objectives and bases for program justification can change frequently. Figure 2 shows schematically how these generalizations can be applied to the methodology previously shown in Fig. 1.

The first question asked in this generalized methodology is whether the candidate experiment contributes to a currently accepted objective. In this generalized case, however, the objectives are expanded beyond those in the application areas. These objectives are monitored as indicated by the broken line in Fig. 2.

If a candidate experiment satisfies a currently acceptable objective, it is then subjected to the benefits sufficiency test as shown in Fig. 1. However, rather than automatically discarding the experiment from further consideration if it does not meet a currently accepted objective, it is suggested that the experiment be subjected to another test in the generalized methodology to determine if there is another valid objective to which the experiment contributes. In particular, one should determine if the experiment supports an objective which, though not of particular importance today, might be of importance in 10 or 20 years. In this way, NASA can improve its ability to respond to the introduction of new national priorities by having previously determined relevant supportive capabilities.

In expanding the set of objectives against which to judge the relevance of candidate experiments, however, it is necessary to recognize

* Private communications with personnel at NASA Headquarters have indicated that the Hearth Objectives listed in Appendix B deal only with applications and that the Hearth Committee also identified other objectives. Thus, this first step may already have been taken.

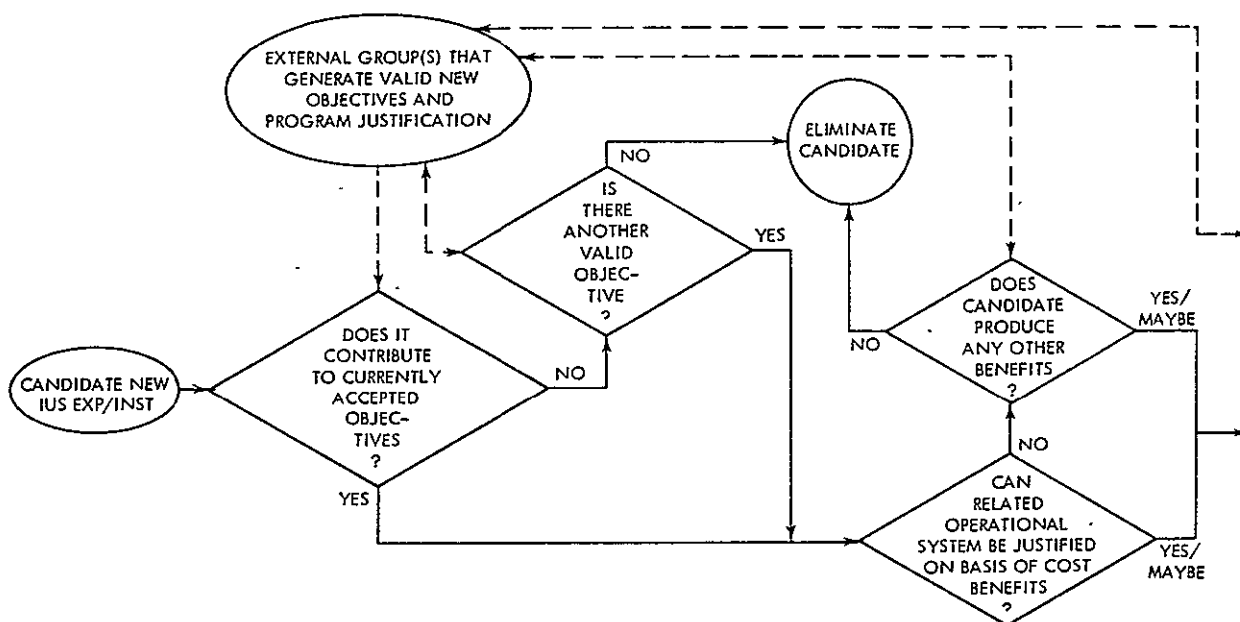


FIG. 2 SCHEMATIC OF GENERALIZED METHODOLOGY FOR JUSTIFYING IUS EXPERIMENTS/INSTRUMENTS

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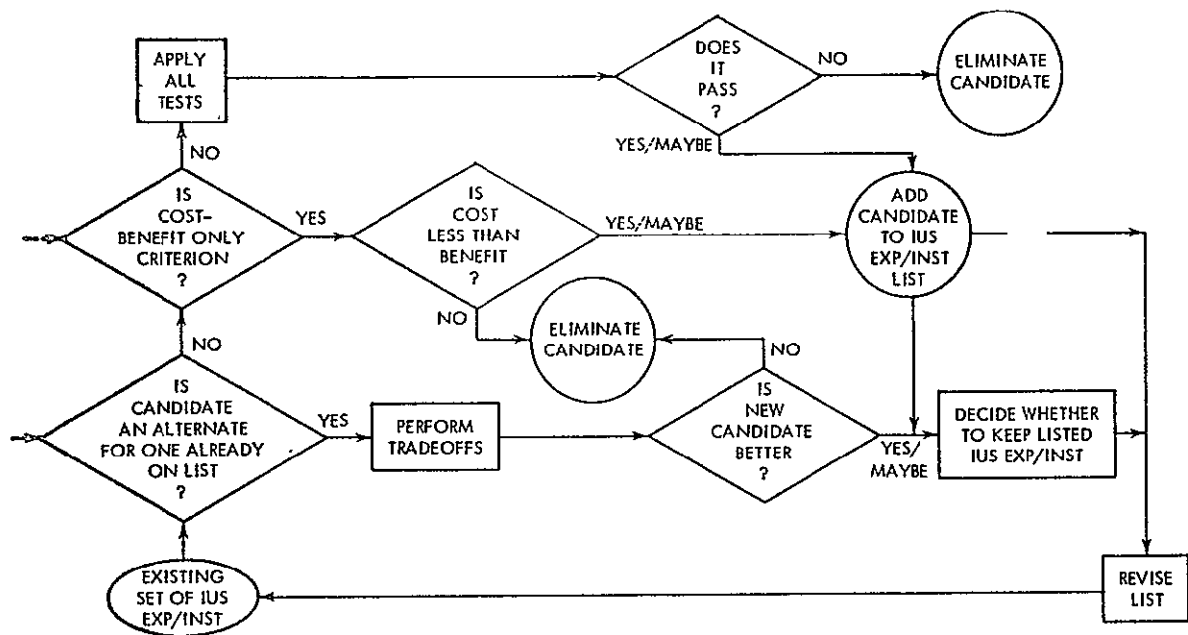


FIG. 2 (CON'T)

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that not all objectives enjoy the same level of importance. For example, those objectives that are not currently recognized but are of potential future significance should be assigned a lower level of importance than those of current acceptance. The monitoring activity schematically shown in Fig. 2 by the dashed lines is of paramount importance in determining the current and projected importance of all objectives since the relative importance changes more rapidly than the list of valid objectives. The difference between objective importance levels is needed as input to the analysis performed in Section III in which justified IUS experiments are subjected to an importance ranking.

If it is determined that the candidate experiment contributes to a valid objective, it is subjected to the benefit analysis operation. As in the analysis shown in Fig. 1, the primary test is to determine if the benefits are greater than the costs.* If so, the analysis continues much as in the case of the simplified analysis shown in Fig. 1. If the costs exceed the benefits, the former methodology would have eliminated the candidate. In the more general analysis, a search for benefits other than cost benefits is made. This is done to permit the survival of basic science, national prestige-generating, and defense-related experiments/instruments that cannot usually be justified merely on a cost-benefit basis. Many of these activities do have a valid place among the justified experiments/instruments.

The next step in the methodology is to determine if the candidate IUS experiment is merely an alternative to an experiment already on the list of justified experiments. If so, the analysis proceeds essentially as in the methodology shown in Fig. 1. If the candidate is not an alternative to one already on the IUS list of justified experiments, then the sufficiency of the candidate's benefits must be assessed. In the generalized methodology, this step requires input from the "outside world"

* As in the simplified analysis, the general methodology calls for a cost benefit analysis using the costs and benefits of the operational system related to the IUS experiment/instrument being considered.

to identify what constitutes a sufficient level of benefits other than cost benefits.

The general methodology discussed here still does not provide much detail for use in the tradeoff analysis performed to determine the "best" of competing alternative technical approaches to satisfy a common need for an operational system. As indicated in the discussion of the specialized methodology shown in Fig. 1, this is outside the current contracted level of effort. There are, however, several comments related to this tradeoff analysis that can be offered without a full investigation. First, the tradeoffs to be performed will have to consider the inherent differences in operational system costs, reliability, weight, and technological risk for different technical approaches. Another observation is that, since the tradeoff analysis for IUS experiments must be performed within the context of a given set of operational systems, the results of this analysis can be interpreted to yield the "best" approach only with reference to this set of operational systems. The use of a different set of operational systems might yield a different "best" IUS experiment; for example, a severe weight constraint in one system may rule out an approach that, although superior in many respects to other options, is too heavy for consideration. Thus, it appears that, unless the operational systems themselves have been shown to be the "best" systems to meet the stated objectives, the IUS experiments labeled "best" in the tradeoff analysis of Fig. 2 must be viewed as "best" in a very limited sense. Unfortunately, the authors have not had documentation that would permit them to verify the Hearth-defined operational systems (or any other) as being optimal. Thus, the analysis performed in this study to determine experiment and payload importance rankings was performed primarily to illustrate how to exercise the derived methodology.

III SELECTION AMONG JUSTIFIED EXPERIMENTS (IMPORTANCE RANKING)

A. INTRODUCTION

The analysis discussed in the previous section enables SRI to identify experiments/instruments that can be justified on generally accepted grounds for possible inclusion in IUS payloads (or other payloads). The scope of the contemplated IUS program, however, is such that not all of the justified experiments can be accommodated on IUS flights. To maximize the return from the IUS missions, therefore, while simultaneously structuring the program to achieve maximum support outside NASA, it will be necessary to judiciously select the payloads to be flown. This selection process consists of two essential steps following the justification of IUS experiments:

- (1) Assessing the inherent value, or importance, of the candidate experiments
- (2) Structuring payloads utilizing experiments of high value that are consistent with spacecraft design characteristics and the availability of non-NASA funding.

This section discusses the method developed by SRI for performing the first of these steps. The criteria to be used are identified and their application is illustrated. Section IV discusses the techniques developed by SRI to perform the formal payload selection process [step (2) above].

B. CRITERIA

The following items have been identified by SRI as reflecting the importance of IUS experiments. Techniques for applying these criteria are discussed in Section C.

- (1) Level of Benefits: The importance of an experiment increases as the level of benefit attributable to the

operational system(s) that it supports increases.* In particular, experiments justified on the basis of hard, demonstrable benefits should be rated higher than those justified on the basis of potential benefits.

- (2) Number of Application Areas Benefited: High importance rankings should be assigned to experiments/instruments that support the development of operational systems that contribute to a large number of application (objective) areas.
- (3) Importance of Areas Benefited: Those experiments that contribute to objectives with a high importance level should, themselves, be assigned a high importance ranking.
- (4) Criticality of Experiment: An experiment required for the development of a beneficial operational system should be assigned a higher importance ranking than an experiment that merely adds a modest increase to that system's capability.
- (5) Timeliness: High importance rankings should be given to those experiments needed to support development of operational systems in the near future; those experiments that can be delayed without impacting the schedule for planned operational system implementation should be assigned a lower importance ranking.
- (6) Special Criteria: There are special cases where unique circumstances merit assigning an importance ranking higher or lower than would ordinarily be given. Examples of such special criteria are:
 - (a) Legislative Action: Congress may, at its discretion, fund activities which ordinarily would not be given a high importance ranking by the methodology developed in this report. Although it is anticipated that such actions would be reflected in the importance assigned to the application areas [see criterion (3) above], such would not necessarily be the case. Thus, one might have to "artificially" upgrade the importance of certain

* Cost benefits constitute the usual type of benefits to be considered in applying this criterion. For other types of benefits, one may still be able to measure the benefits, in which case the instrument can still be meaningfully subjected to the first five criteria. The more likely situation, however, is that special criteria will have to be used to assign an importance rating to experiments justified on grounds other than cost benefits.

IUS experiments. Conversely, legislative action might be taken to suppress certain activities contemplated by NASA and a downgrading of an experiment's nominal importance ranking might be in order.

- (b) Previous Commitments: There may be programs already underway to which NASA or other agencies have made commitments that require flying an IUS experiment nominally assigned a low importance ranking. If the decision is made to retain the commitment, the relevant experiment should be upgraded in importance in order to assure its inclusion in an IUS payload selected using the methodology presented in Section IV.
- (c) National Prestige: Some experiments may be needed to assure a continued high level of U.S. prestige, for example, in the area of space-based telecommunications where the Japanese and others are developing comparable capabilities. Consequently, the pressures to maintain national prestige may also dictate increases in the nominal importance ranking given certain IUS experiments.

The above criteria have been derived heuristically. Past experience with NASA and non-NASA activities confirms their validity. However, the straightforward application of these criteria does not yield a unique rank ordering of experiments. For example, consider the simple case of trying to rank order two of the candidate IUS experiments/instruments shown in Table 1, the cesium ion engine and the 1.5-meter telescope radiometer. Using Criterion 2 above, the data in Table 1 indicate that the cesium ion engine should have the higher importance ranking: it supports 25 objectives versus 18 for the radiometer. However, Criterion 4 would indicate a higher priority for the radiometer since it is a critical experiment/instrument for several objectives. Therefore, techniques are needed to permit application of these criteria to yield meaningful importance rankings among candidate IUS experiments/instruments. The following section discusses the techniques developed by SRI.

C. IMPORTANCE RANKING TECHNIQUES

The above discussion identifies several criteria that will influence the rankings of candidate IUS experiments by importance. SRI has derived

a method whereby all these criteria can be applied to each experiment to determine its importance. There are two basic requirements for this process.

- (1) One must be able to assign a "partial importance" rating to each experiment where a "partial importance" of an experiment is that associated with a single criterion.
- (2) Some procedure must be generated to combine the individual "partial importances" into a single, final importance rating.

For example, the assignment of "partial importances" for Criterion 1 might be accomplished by first listing candidate IUS experiments in order according to the level of benefits occurring from the pertinent operational systems. This rank ordering could then be used to generate a normalized, "partial importance" rating for Criterion 1 by dividing the benefit assigned to each experiment by the maximum benefit appearing in the list. Assigning "partial importance" ratings on the basis of Criterion 4 (Criticality of Experiment) would involve grouping the experiments into a small number of sets and assigning each set a single criticality level. A complete rank ordering would not be required in this latter case.

The determination of "partial importances" is conceptually simple and has been shown to be feasible in its application in such widely disparate areas as proposal evaluation and personnel merit reviews, where it is applied to yield the equivalent of "partial importances" in each of the pertinent evaluation areas (for example, productivity, creativity, and management skills in the merit review process).

"Partial importance" assignments should or can be made for Criteria 1 through 5; however, the Special Criteria (No. 6 in the list given) need not be included in this treatment for two reasons. First, many such criteria serve to define an importance ranking mandated by authority, thereby negating the need for a detailed analysis. Second, in the remaining cases these criteria dictate a modification to the nominal importance rating derived from the first five criteria but on grounds that are almost unique to each specific case, thereby dictating individual consideration.

The procedure for combining the individual "partial importances" into a single importance rating used for rank ordering the IUS experiments must, at least implicitly, reflect the relative importance of the criteria and the interdependence of the criteria. For example, in some proposal evaluation exercises, the final score is merely the sum of the numerical ratings in the individual evaluation areas, with a maximum possible score being specified in each area. In this case, the maximum possible scores serve as a direct measure of the weights attached to the evaluation criteria and the procedure of summing the individual scores indicates that the evaluation criteria are viewed as essentially independent (for example, the "partial importance" rating for an excellent technical approach in a proposal would be unaffected by a low rating on personnel qualifications). Another approach to combining "partial importances" into a single importance rating involves multiplying the individual scores together rather than summing them. This method, in essence, assumes a dependence between evaluation areas so that a low personnel qualifications score would tend to discount a high score for a proposal's technical approach. Regardless of the procedure used, however, it represents an attempt to make objective what is in reality a subjective process of combining quantities appropriately measured in different units into a single figure of merit.

In attempting to rank order IUS experiments using a set of at least five criteria, the above observations indicate that a large number of methods could be used for determining the final, single importance rating for each experiment. The acceptability of any one method, however, should be tested empirically. Although it is beyond the scope of this study to demonstrate empirically the validity of any one method, SRI has constructed the following method that yields reasonable results:

- (1) Select an experiment.
- (2) Identify all objectives benefited by this experiment.
- (3) Determine the costs and benefits attributable to the experiment using the methods outlined in Section II-B.3. Calculate the level-of-benefits, "partial importance,"

parameter A.* This parameter is defined to provide higher "partial importance" ratings to experiments that are justified on the basis of hard, demonstrable benefits:

- (a) If the experiment has associated hard benefits exceeding its associated system costs, set $A = (1+R)/2$ where R is the ratio of hard benefits minus system costs (for this experiment) to the maximum value of this quantity (for all experiments considered). Thus, $A = 0.5$ for a case where hard benefits are equal to system costs and equals the maximum value of 1.0 for that experiment with maximum cost benefits.
- (b) If the experiment must be justified on the basis of total, rather than hard benefits, then set $A = 1/2 R'$ where R' is defined as the ratio of hard benefits to system costs for this experiment. This second definition of A yields $A = 0.5$, as above, when the hard benefits equal the associated system costs.

(4) For each objective benefited:

- (a) Determine the importance of the objective and assign it a value B between 0 and 1. For example, let $B = 1$ for communications (Hearth Objectives 034, 051, and 052), severe storms (Hearth Objective 031), crop forecasting (Objective 011), and water availability (Objective 012) with $B = 0.5$ for all other objectives.**

* For simplicity, we restrict the discussion of SRI's method to cost benefits. It was previously noted that special criteria may be available to assign importance ratings to many experiments justified by other benefits. For those cases where special criteria are not available to effect this rating, however, it will be necessary to assign an appropriate "partial importance" rating based on level of benefits. This can be accomplished by defining a conversion factor which states the dollar benefit equivalence of each unit of benefit. For example, an experiment justified on the basis of lives saved can be assigned a dollar benefit once the monetary worth of a life is defined. The resulting monetary benefit can then be used to assign the experiment its proper place in the existing list of experiments justified on the basis of cost benefits, just as if the experiment had an equivalent cost benefit associated with it.

** This assignment is somewhat consistent with the emphasis currently being placed on the development of operational space systems.

- (b) Determine the criticality of the experiment and call it C. For example, let C = one third of the appropriate numerical entry in Table 1. This method normalizes C to values between 0 and 1.
- (c) Determine the timeliness factor D. For example, let D = 2 for those experiments for which early flight is critical, D = 1 for those experiments for which early flight is desirable, but not required, for timely development of the related operational systems, and D = 0.5 for those experiments that support operational systems to be fielded well into the future.
- (d) Form the product BCD.
- (5) Sum over all products BCD for this experiment and multiply by A. This is the final, single importance rating for this experiment.
- (6) Select another experiment and go to step (2) until all experiments are analyzed.
- (7) Rank the experiments in order of their final importance ratings.

SRI has applied this method to the IUS experiments listed in Table 1. In that analysis, the quantity A (the "partial importance" rating for an instrument's benefits) was set equal to 1.0 for all cases. This action was taken, even though the definition of A implies that A is actually less than unity in every case but one, because the benefit analyses required to compute A are not possible with the available data. The results of the SRI analysis are shown in Table 4 under the assumption that $D = 1$ for all cases (see step 4c in the importance ranking method). This constant value of D was used since the operational systems and their deployment schedules were not defined for the Fairchild set of experiments/instruments.

The highest importance rating derived for the experiments in Table 1 was 10.8, as shown in Table 4. The derived importance ratings have been normalized by dividing each rating by this maximum value. The resulting normalized ratings have been categorized into five levels of importance with the following nominal ranges:

Table 4

RELATIVE IMPORTANCE RANKING RESULTING FROM SAMPLE RATING METHOD

Importance Level	Fairchild Experiment/Instrument	Importance Rating	Normalized Rating
High	1.5-m Telescope Radiometer	10.8	1.0
	Integrated Communication Experiment	10.7	0.99
	Ion Engine	10.3	0.95
	Microwave Vertical Atmospheric Sounder	10.3	0.95
	Microwave Measurement of Temperature and Water Vapor Profiles	9.5††	0.88††
	Geosynchronous Cloud Physics Radiometer	9.0	0.83
	Data Collection System	8.8	0.82
Moderately High	Stereo Severe Storm Sensing	7.5	0.70
Moderate	Millimeter Wave Communication Experiment	5.8††	0.54††
	Atmospheric X-Ray Emission Detector	5.5	0.51
	Fixed and Mobile Satellite Communication	5.3	0.49
	Multibeam Experiment	5.3	0.49
	Millimeter Wave Broadband Experiment	4.8	0.44
	Fuel Cell	4.7	0.44
	EM Environment Experiment	4.7††	0.44††
	RFI Investigation		
	Radar Measurement of Precipitation Rates Over the Ocean	4.7	0.44
	CO2 Laser Data Relay Experiment	4.7	0.44
Moderately Low	Orbital Antenna Range	4.3	0.40
	Orbiting Standards Platform	4.3††	0.40††
	Hydrometer Attenuation/Depolarization Experiment	3.8	0.35
	Millimeter Wave Satellite-to-Satellite Experiment	3.8	0.35
	Liquid Metal Slip Rings	3.3	0.31
	Geosynchronous Laser Reflector	3.2	0.30
	Eclectic Satellite Pyroheliometer	3.2	0.30
Low	High Voltage Solar Array Experiment	3.0	0.28
	Radar Interferometry Locator	2.2	0.20
	PADS **	2.0	0.18
	PATTI **	2.0	0.18
	Relay Station for Deep Space Probes†	0.0	0

* As discussed in main report, apparently only one of these is needed.

** Low rankings for PADS and PATTI due to lack of explicit identification of areas of application in Table 1. Additional information could markedly change the rankings assigned.

† Inclusion in list not justified on basis of Hearth Objective.

†† Inclusion of these experiments in the Integrated Communication Experiment implies that these nominal ratings should actually be set equal to zero.

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<u>Importance Level</u>	<u>Normalized Rating Range</u>
High	0.8 to 1.0
Moderately High	0.6 to 0.8
Moderate	0.4 to 0.6
Moderately Low	0.2 to 0.4
Low	0.0 to 0.2

The grouping of experiments in Table 4 is consistent with this categorization.

The ranking in Table 4 appears reasonable, since the IUS payloads proposed by Fairchild and GE are made up primarily of instruments near the top of the rank-ordered list. The rankings should be viewed as preliminary, however, since the input data to the importance rating paradigm are, themselves, preliminary and incomplete. The validity of the rankings shown in Table 4 should be considered with the following caveats:

- (1) The "partial importance" parameter A for the level-of-benefits was set equal to unity for all experiments. It was not possible to calculate A for each experiment because the operational systems for the list of instruments have not been adequately defined. Therefore, neither the hard benefits nor the total system costs were available to compute A. The cost-benefit analyses for selected Hearth systems in Section II.B.3.d, however, show that values of less than 0.5 can be anticipated for the factor A. Thus, subsequent analysis with more complete data will reduce the importance ratings of many of the experiments listed in Table 4.
- (2) The ratings in Table 4 were derived using the criticality factor (C) shown in Table 1. The entries in Table 1, however, must be considered preliminary until the operational systems corresponding to the experiments/instruments are well defined. When these operational systems are defined, a new table can be constructed which will reflect realistic estimates of the experiment/instrument criticality. Some new entries will be added, and the criticality ratings of existing entries will probably be modified either upward or downward. For example, PATTI and PADS may have much higher importance levels than shown in Table 4, when subjected to the importance rating exercise using the complete input

data, because of their intended use in operational systems to provide accurate pointing and precise time control capabilities, which are critical to optimization of these operational systems.

- (3) The timeliness factor (D) used in this rating exercise was also set equal to unity in deriving the ratings shown in Table 4 because the operational systems and their implementation schedules were not defined. However, more appropriate values can be determined when valid data are available. For example, depending upon the operational systems' deployment schedule, the Ion Engine may not be required before the middle 1990's when the number of communication satellites and their users becomes so large as to require a very accurate station-keeping capability. Thus, $D = 0.5$ may be appropriate for this experiment/instrument in its application to communications. Similar observations apply to the use of this instrument for Power Relay (the capability will probably not be needed until many years after IUS flights). Consequently, reducing D to 0.5 for the related Hearsh Objectives for these example cases would reduce the normalized importance rating from 0.95 to 0.85, which is still within the High Importance Level category.
- (4) None of the Special Criteria discussed earlier in this section were applied in determining the importance ratings in Table 4 and only the Hearsh Objectives identified in Appendix B were used to define the application areas considered. Consequently, although the Relay Station for Deep Space Probes was assigned an importance rating of 0.0, it will have a higher rating if a space science objective is added to the existing Hearsh Objectives, or if NASA has committed this instrument to an approved deep space mission.

Although the rankings shown in Table 4 should be considered preliminary, the paradigm presented on pages 45-47 of this report has been shown to be feasible in application and to yield appropriate importance rankings based on the preliminary input data available and the criteria identified. A conclusive rank ordering, however, will depend upon provision of accurate and complete input data.

IV PAYLOAD SELECTION

A. CRITERIA

The methods outlined in the previous sections permit the assignment of importance levels to justified IUS experiments/instruments. If a larger number of IUS flights were contemplated, it would not be necessary to rank-order the justified experiments/instruments; all could be flown. However, the number of IUS missions anticipated will not accommodate all potentially beneficial IUS experiments/instruments. Therefore, the rank-ordering has a useful role in the decision process to determine what payloads should be flown on the IUS. This section shows how this rank-ordering of experiments is utilized in the payload selection process and identifies other criteria that should be considered in this process.

The rationale to be applied in the payload selection process are those that meet the following criteria:

- (1) Technical Compatibility - The experiments/instruments that make up a given payload must be selected so as to conform to the weight, power, and volume constraints of the spacecraft. This is a firm requirement not just a desired attribute.
- (2) Experiment Importance - A payload should be made up of IUS experiments/instruments of high importance. Doing so would assure broad support for the program. It should be recognized, however, that although a high importance ranking implies a large benefit from the related operational system (criterion 1 in Section III-B), there may be more than one development activity required to field the operational system in question. This observation leads to the following criterion.
- (3) Experiment Completeness - Following the selection of a given IUS experiment for an IUS payload, one should ensure that the other experiments needed to complete development of the related operational system are also scheduled for flight. If this rule is not followed, one ends up with a partially developed system of potentially large, yet indeterminant, benefit. However, in applying this rule, it should be recognized that every experiment relevant to a given

operational system need not be flown on IUS: other, non-IUS, payloads may well furnish the test bed for some of these experiments.

- (4) Sponsorship - Preference should be given to those experiments/instruments that analysis has shown to have a high probability of being financially sponsored by agencies other than NASA. Such an experiment is still subject to the desiderata under (2) and (3) above, just as is any other experiment. The inclusion of sponsored experiments on IUS payloads serves as a very visible endorsement of the program and it expands the IUS program beyond the limits imposed by a fixed level of NASA funding.
- (5) Time-Phasing - The scheduling of IUS payloads and the assignment of specific experiments should be tailored to the budgetary capabilities of the potential sponsors. For example, if a large number of experiments are candidates for funding by a single sponsor but only at an annual funding level that precludes flying all the experiments on a single payload, the experiments should be divided among several payloads in order to match the sponsor's financial capability and the experimental funding requirements.
- (6) Immediacy - The IUS payloads should be selected to show preference to those experiments which support immediate rather than delayed deployment of the related operational system. There are two reasons for this: First, it provides early visibility to practical results which can be expected from the entire STS program, thereby reinforcing the basis for the program and enhancing the early recruitment of additional support. Second, it permits the appropriate time-phased division of activities between IUS and the Space Tug. This division must be made to optimize the benefits not only from IUS but the Tug as well, since IUS cannot handle all beneficial experiments.
- (7) Spacecraft Utility - In applying the constraint expressed in (1) above to spacecraft capacity, one may find that the high-importance experiments under consideration are so sized that they cannot be grouped to utilize all spacecraft capacity for a given payload, leaving some small capacity that is too small to accommodate one of the high-importance items. Under these circumstances the IUS payload configuration should be completed with the addition of experiments of lower importance to avoid under-utilization of spacecraft capacity. One important option which should be considered is the use of any excess space, weight, and

power (all three must be available) for basic science experiments. This approach is consistent with the philosophy expressed in Section I-A and Appendix A of this report: basic science should be supported but as a subsidiary objective. If this approach is used, universities and other institutions interested in scientific research should be apprised of the available experimental conditions in time to permit coordination of their (probably) small experiments with the other elements of the appropriate payloads.

The above criteria characterize the desired attributes of important IUS payloads. They are not in a form, however, that permits assigning a unique importance rating to candidate IUS payloads nor do they enable one to structure the "most important" IUS payload from a given list of IUS experiments and instruments. To perform these operations, one needs a quantitative payload importance function that assigns each payload an importance rating consistent with the criteria listed. The following section defines such a function. The importance function is utilized in a subsequent section where a technique is developed to structure the "most important" IUS payload from a list of IUS experiments/instruments. The technique is further developed so that a series of payloads can be identified, in decreasing order of importance, subject to the condition that each payload is the "most important" possible given the selection of its predecessors in the series. In this process, it will be necessary to apply an additional criterion to preclude unnecessary duplication of experiments on IUS payloads:

- (8) Non-Duplication - In spite of what importance rating might otherwise be assigned an IUS payload, its importance should be greatly diminished if it contains an experiment/instrument included on a previously selected payload. An exception to this general rule should be granted if the instrument performs a different function in the payload being evaluated. Such a case arises when a previously used instrument is needed to provide supporting services to an experiment/instrument that has not been included on a previously selected payload.

This eighth, and last, criterion has a marked impact on any attempt to assign an importance rating to an IUS payload. The criterion implies that the importance rating assigned to an IUS payload is dependent upon

what other payloads have been selected, and this is reasonable because the need to perform any R&D or operational activity depends upon whether or not the work has already been scheduled for execution. However, the criterion does introduce a complexity into the payload importance function that was not present in the experiment/instrument importance function discussed in Section III.

B. DEFINITION OF PAYLOAD IMPORTANCE FUNCTION

As previously noted on page 45 of this report, the procedure for assigning a single importance rating to a payload or experiment is in essence an attempt to make objective the subjective process of combining quantities appropriately measured in different units into a single figure of merit. Thus, as in ranking experiments/instruments by importance, there are many possible formulas for combining the "partial importances" of IUS payloads into a single, well-defined payload importance rating, consistent with the eight criteria identified. The particular formula presented below satisfies the eight criteria and appears to yield reasonable payload importance rankings. However, the acceptability of the specific form used must be judged on the basis of real-world usage.

As was done in assigning importance levels to IUS experiments, SRI has defined a "partial importance" parameter for each of the relevant criteria. These individual "partial importance" factors for the payload importance function are:

- (1) Technical Compatibility (TC)
- (2) Experiment Importance (EI)
- (3) Experiment Completeness (EC)
- (4) Sponsorship (S)
- (5) Time-Phasing (TP)
- (6) Immediacy (I)
- (7) Spacecraft Utility (SU)
- (8) Non-Duplication (ND).

SRI has combined these eight "partial importance" factors to form a number of payload importance functions, all consistent with the eight

specified criteria. Of the numerous functions generated, the following form appears to be the best choice; it assures consistency with the criteria while simultaneously generating heuristically reasonable payload importance ratings in a straightforward manner that can be adapted to yield unambiguous selection of the most important payload and an ordered series of the less important payloads:

$$PI = (TC)(EC)(SU)(TP) \sum_i (ND)_i (EI)_i (1 + S_i + I_i) (W_i / \sum_j W_j)$$

In this equation, PI is the payload importance rating; TC, EC, SU, TP, ND, EI, S, and I are the "partial importances" identified above; the subscript i labels a quantity defined for the ith experiment/instrument; W_i is the weight of the ith experiment; and both summations (i,j) are over all experiments in the payload. The values for each of the quantities on the right-hand side of the equation are to be assigned as described below. The consistency of these assignments with the eight criteria specified is identified.

- (1) The variable TC is to be assigned a value of 1.0 if the experiments/instruments on the payload can all be accommodated within the weight, volume, power, and other capacity limitations of the spacecraft. If any such limitation is exceeded, TC is set equal to zero. This assignment of TC values assures complete consistency with Criterion No. 1, Technical Compatibility.
- (2) The Experiment Completeness "partial importance" (EC) is set equal to unity if both of the following conditions are met:
 - (a) The payload, whose importance rating (PI) is being calculated, contains those supporting instruments needed to optimize the performance of each experiment in the payload.
 - (b) The other experiments required to field the related operational system for each experiment in the payload are included either on an IUS payload in the set of defined IUS payloads or in some non-IUS program.

In all other cases, EC is set equal to zero. This definition of EC actually makes Criterion No. 3 (Experiment Completeness) a requirement rather than a desired attribute (as could be achieved by letting EC take on values between 0 and 1 for less than full experiment

completeness). However, SRI feels that, since the opportunity still exists to configure IUS payloads optimally, this criterion should be viewed as a requirement to aid identification and selection of these optimal, complete payloads.

- (3) The Spacecraft Utility parameter (SU) is defined as the ratio of the total weight of the experiments included in the payload to the weight capacity for experiments on the spacecraft. This definition of SU and the appearance of SU as a multiplier in the equation for PI assure compliance with Criterion No. 7, Spacecraft Utility. This definition of SU tends to yield higher PI values for payloads that are limited by spacecraft weight capacity rather than by power or volume constraints, because the total weight of experiments in these latter cases will be less than the spacecraft's weight capacity. SRI feels that favoring weight-limited payloads is appropriate because of the political wisdom in maximum utilization of weight capacity, the most expensive to increment. Failure to assign higher importances to payloads that are primarily weight-limited could easily generate a credibility problem for NASA: its critics could question NASA's objectivity in calling for the development of a system of greater payload weight capacity than is apparently needed, at a cost exceeding that of a system more in keeping with the weight capacity utilized in IUS flights.
- (4) The quantity $(EI)_i (1 + I_i + S_i)$ is defined as the Payload Related Importance Factor for the i^{th} experiment/instrument $[(PRIF)_i]$, where:

$(EI)_i$ = the i^{th} experiment's normalized importance rating (see Table 4)

S_i = the assessed probability that a sponsor outside NASA will financially assist in flying the experiment

$I_i = \begin{cases} 1, & \text{if the experiment offers an operational capability or if the experiment is needed to provide immediate information for a developmental program*} \\ 1 - \frac{n}{20}, & \text{if the experiment supports the development of an operational system scheduled for initial deployment } n \text{ years after the IUS flight.} \end{cases}$

* For example, the PATTI experiment should be assigned an immediacy factor, I , of unity since the results of the experiment are needed to define the PATTI requirements for Spacelab.

This term is defined consistent with the desiderata of Criteria Nos. 2, 4, and 6 (Experiment Importance, Sponsorship, and Immediacy, respectively).

- (5) The Time-Phasing "partial importance" parameter (TP) is defined to be zero if the experiments on the payload place too large a burden on any one potential sponsor's budget. In all other cases, TP is set equal to unity. This definition assures complete consistency with Criterion No. 5.
- (6) The value of $(PRIF)_i$ as calculated above should be left unchanged for a given experiment if the experiment has not been scheduled for inclusion on the same or a previously configured IUS payload. If the experiment has been previously scheduled for IUS flight and if the instrument would perform no additional function onboard the IUS payload being considered, then the effective PRIF for this experiment on this payload should be set equal to zero. Some residual importance, however, should be assigned the experiment/instrument if, even though scheduled previously on another IUS payload, it provides a support function that optimizes the performance of another experiment slated for inclusion on the payload being considered. Consequently SRI has treated the "partial importance" parameter ND_i as a multiplicative factor of PRIF where:

$$ND_i = \begin{cases} 1, & \text{if the } i^{\text{th}} \text{ experiment has not previously been} \\ & \text{included on IUS payload} \\ 0, & \text{if the } i^{\text{th}} \text{ instrument has already been sched-} \\ & \text{uled for inclusion on an IUS payload and would} \\ & \text{perform no new function on the payload under} \\ & \text{consideration} \\ A, & \text{if the } i^{\text{th}} \text{ experiment, although previously} \\ & \text{scheduled for an IUS payload, performs a needed} \\ & \text{support function for another experiment included} \\ & \text{on the payload under consideration.} \end{cases}$$

SRI has specifically defined A to be the lesser of

- (a) 1, and
- (b) $(PRIF)_j' / (PRIF)_i$, where $(PRIF)_j'$ is the maximum values of $(PRIF)_j$ of all j^{th} experiments is supported by the i^{th} experiment

This definition of A assures that PRIF for a support experiment is assigned its nominal value for its initial inclusion on an IUS payload, but its PRIF is constrained to values no larger than those of the experiments it

supports for its inclusion on subsequent payloads.
This definition of $(ND)_i$ assures compliance with the eighth, and last, criterion (Non-Duplication).

The $(W_i / \sum_j W_j)$ factor in the equation for PI essentially weights the contribution from each experiment to the overall payload importance by the fraction of the total experiment weight of the payload attributable to this experiment. Thus, one may view the equation for PI as defining the payload importance in terms of a normalizing factor (the terms to the left of the first summation sign) times the average "effective PRIF" of the experiments on the payload where the "effective PRIF" for the i^{th} experiment is $(ND)_i (PRIF)_i$.

C. SELECTION OF IMPORTANT PAYLOADS

Because it is anticipated that limited resources will preclude flying all proposed IUS experiments/instruments, a technique for assigning an importance level to individual payloads was generated to assure that the greatest benefit would be obtained from the IUS payloads actually flown. The payload importance function generated by SRI can be used to determine which of a proposed set of payloads have the highest importance levels and, therefore, should be pursued to satisfy the objective above. However, such an exercise does not guarantee the selection of the most important payloads possible, merely the selection of the most important ones among those proposed, unless the set of proposed payloads contains all possible payloads. Thus, although the payload importance function permits the rank ordering of proposed payloads, the complete optimization of the benefits to be derived from orbiting less than the complete set of IUS experiments/instruments involves either (1) generating and rank-ordering an enormous number of candidate payloads or (2) applying a method that will identify the most important IUS payloads that can be structured from the list of experiments. The former approach requires too large a volume of effort even for a small number of IUS experiments. Therefore, SRI has attempted to develop a method whereby the most important IUS payloads can be identified without having to examine all possible payloads. The following paragraphs discuss this effort.

The problem of determining the most important IUS payloads possible was approached by first attempting to generate a method whereby a single, most important payload could be synthesized. This particular payload would have associated with it the maximum value of

$$PI = (TC)(EC)(SU)(TP) \sum_i (WD)_i (EI)_i (1 + S_i + I_i) (W_i / \sum_j W_j)$$

where the sum is over the candidate IUS experiments. SRI attempted to restructure this function in terms of a well-defined linear or non-linear objective function so that previously developed algorithms could be used for its solution. Considerable success was made in this direction. Specifically, SRI found that, using the definitions of the previous section, the problem of selecting the most important IUS payload reduces to maximizing the objective function

$$\sum_i (PRIF)_i W_i X_i / W_T(X)$$

where the variables $\{X_i\}$ to be found are restricted to the values 0 and 1 such that

$$X_i = \begin{cases} 1, & \text{if the } i^{\text{th}} \text{ experiment is included in payload} \\ 0, & \text{if it is absent from the payload} \end{cases}$$

and where $W_T(X)$ is the maximum weight of the experiments that can be carried in the spacecraft. The quantity W_T is in general function of the X_i 's since, for example, the weight of the power supplies needed for a set of experiments can vary from one set to another. SRI has addressed this general case, but, for the sake of simplicity, the following discussion is specific to a fixed W_T . For this case, the objective function is to be maximized subject to the following conditions:

- (1) $\sum_i W_i X_i \leq W_T$
- (2) $\sum_i V_i X_i \leq V_T$ where V_i is the volume of the i^{th} experiment and V_T is the total experimental volume available.
- (3) $\sum_i P_i X_i \leq P_T$ where P_i is the power required for the i^{th} experiment and P_T is the total power available. These

first three conditions assure compliance with Criterion No. 1.

- (4) $\sum_i A_{ij} X_i \leq A_j$ (for all j) where A_{ij} is the cost to sponsor j of experiment i and A_j is the financial capacity of this sponsor. This inequality assures compliance with Criterion No. 5.
- (5) Let the i^{th} experiment be one that supports one or more experiments. Let $B_{ij} = 1$ if the j^{th} experiment requires the presence of the i^{th} experiment to realize optimal performance of the j^{th} experiment. Let $B_{ij} = 0$ for all other cases. Then, the variables X_i must satisfy the condition

$$X_j - B_{ij} X_i \leq 0 \text{ (for all } i \neq j \text{)}$$

for each j . This assures partial compliance with Criterion No. 3 (Experiment Completeness).*

The objective function, as written, reflects the inclusion of Criteria No. 2, 4, 6, and 7. The restriction of X_i to values of 0 or 1 assures observation of Criterion No. 8 (Non-Duplication). Thus, the defined objective function and the above mathematical constraints completely characterize the problem of determining the most important IUS payload possible from a list of candidate experiments, subject to the stated simplifications that $W_T(X)$ is independent of the X_i 's and that only a portion of Criterion No. 3 has been explicitly included in the formulation. The maximum of the objective function can be found, subject to the given conditions on the X_i 's, by utilizing a modified form of the Partial (Implicit) Enumeration Algorithm. The particular modification to be used

* Full compliance with Criterion No. 3 involves a further condition to assure that, if one experiment contributing to the development of a given operational system is included on any one IUS payload, the other experiments required for this operational system appear either on an IUS payload in the set defined or on other non-IUS programs. The introduction of this condition requires the addition of another subscript or the variables X_i to denote in which IUS payload a given experiment appears. The funding level and manpower constraints on the current effort precluded SRI from exhibiting the mathematical form of this inter-payload completeness test. However, the general form is known. Its imposition will not invalidate the utility of the algorithm subsequently identified for solving the optimization problem.

is discussed in Reference 9. The investigations of SRI indicate that this same algorithm can still be used when the two cited simplifications are relaxed. The algorithm does not require the examination of each and every possible payload in order to determine the optimal payload. The algorithm apparently was coded for use on a computer as early as 1970. Therefore, the objective of finding a method, short of examining all possible payloads, to identify the most important payload possible (consistent with the payload importance function defined by SRI) has been achieved.

Only slight modifications to the above procedure are needed to determine the next most important IUS payload possible, given the selection of the first n ($n \geq 1$) most important payloads. The required modifications are:

- (1) Any non-supporting experiment/instrument must be removed from consideration if it has been included on a previously selected payload. This condition is easily expressed mathematically in terms of the X_i 's for the payloads previously selected.
- (2) For a supporting experiment/instrument, the condition

$$X_i - \sum_{j \neq i} B_{ij} X_j \leq 0$$

must be met if the i th (supporting) experiment has been included on a previous payload. This assures inclusion of the i th (supporting) experiment only in a supporting role.

- (3) For any previously scheduled supporting experiment, its $(PRIF)_i$ must be restricted to the maximum of its nominal value and the $(PRIF)_j$ of the experiments/instruments it supports in the payload under consideration. This condition can be mathematically expressed as a non-linear equation involving the X_i 's from the payload being synthesized and the previously selected payloads.

These three modifications produce a non-linear objective function for PI, the payload importance, even if $W_T(X)$ is a constant. However, the modified Partial Enumeration Algorithm is still applicable. Thus, the desired objective of determining a method to obtain an ordered list of the most important IUS payloads possible, without examining all

possible payloads, has been achieved. Indications are that the required algorithm has already been coded for use on an electronic computer. But even if this has not been done, it is a straightforward exercise to do so.

D. EXAMPLE APPLICATIONS

The payload importance function (PI) defined above and the technique outlined for selecting an ordered set of the most important IUS payloads possible for a given set of candidate IUS experiments/instruments require a larger set of input than was available to SRI in the course of this study effort. This is evidenced by Table 5 wherein is displayed nearly all the pertinent input data available to SRI for use in payload importance rating and payload selection exercises. In this table, the values of EI are those obtained by SRI in Section III*; each Sponsorship factor shown reflects SRI's assessment of the current probability that a sponsor outside NASA will fund the given experiment, and the Immediacy factors listed reflect our best judgment as to the deployment dates of the corresponding operational systems. The weights shown for the experiments are those given in the Fairchild material made available to SRI by GSFC personnel. Absent from Table 5, however, are data on experiment volume and power requirements, funding capabilities of potential sponsors, and other required input data.

The lack of a complete input data base implies that any example usage of the payload importance function (PI) or the technique to select an ordered set of important IUS payloads will serve only to illustrate their application and that any resulting payload importance ratings should be viewed as gross, preliminary estimates. The need to view any such calculated payload importance levels as preliminary is further justified by noting that the EI values available for use from Table 5 are themselves

* The individual components of the Integrated Communication Experiment (ICE) are shown in Table 5 in their nominal experiment importance ranking but with their EI's set equal to zero as appropriate for these duplicate experiments. The Data Collection System, although also a component of the ICE, retains its non-zero EI, however, because it serves as a supporting instrument for other candidate experiments.

Table 5
WORKSHEET FOR SELECTING IUS PAYLOADS

Experiment Importance Level	Fairchild Experiment/Instrument	Normalized Experiment Importance Rating (EI)	Sponsorship Factor (S)	Immediacy Factor (I)	Payload-Related Importance Factor (PRIF)	Weight (W) in kg	PRIF x Weight in kg
High	1.5-m Telescope Radiometer	1.0	1.0	0.7	2.70	600	1620
	Integrated Communication Experiment	0.99	1.0	0.9	2.87	225(?)	646
	Ion Engine	0.95	0.9	0.5	2.28	34 to 42	78 to 96
	Microwave Vertical Atmospheric Sounder	0.95	0.9	0.7	2.47	73	180
	Microwave Measurement of Temperature and Water Vapor Profiles††	0.00	0.9	0.7	0.00	45	0
	Geosynchronous Cloud Physics Radiometer	0.83	1.0	0.9	2.41	96	231
	Data Collection System	0.82	1.0	0.9	2.38	40 to 45	95 to 107
Moderately High	Stereo Severe Storm Sensing	0.70	0.9	0.8	1.89	NA*	NA
Moderate	Millimeter Wave Communication Experiment††	0.00	1.0	0.7	0.00	45	0
	Atmospheric X-Ray Emission Detector	0.51	0.9	0.7	1.33	45	60
	Fixed and Mobile Satellite Communication	0.49	1.0	1.0	1.47	NA	NA
	Multibeam Experiment	0.49	1.0	1.0	1.47	68	100
	Millimeter Wave Broadband Experiment	0.44	1.0	0.8	1.23	NA	NA
	Fuel Cell	0.44	0.8	0.7	1.10	10	11
	EM Environment Experiment††	0.00	1.0	0.9	0.00	90	0
	Radar Measurement of Precipitation Rates Over the Ocean	0.44	0.7	0.5	0.97	NA	NA
	CO ₂ Laser Data Relay Experiment	0.44	0.7	0.5	0.97	41	40
Moderately Low	Orbiting Standards Platform††	0.00	0.8	0.7	0.00	80 to 90	0
	Orbital Antenna Range	0.40	0.8	0.7	1.00	NA	NA
	Hydrometer Attenuation/Depolarization Experiment	0.35	0.5	0.5	0.7	NA	NA
	Millimeter Wave Satellite-to-Satellite Experiment	0.35	0.8	0.7	0.88	NA	NA
	Liquid Metal Slip Rings	0.31	0.5	0.5	0.62	NA	NA
	Geosynchronous Laser Reflector	0.30	0.7	0.7	0.72	23	17
	Eclectic Satellite Pyroheliometer	0.30	0.5	0.4	0.57	NA	NA
	High Voltage Solar Array Experiment	0.28	0.7	0.7	0.67	7	4.7
Low	Radar Interferometry Locator	0.20	0.7	0.8	0.5	NA	NA
	PADS**	0.18	0.7	0.8	0.45	38	17
	PATTI**	0.18	0.7	1.0	0.49	10	4.9
	Relay Station for Deep Space Probes†	0.0	0.2	0.2	0.0	NA	0.0

* Not available.

** Low rankings for PADS and PATTI due to lack of explicit identification of areas of application in Table 1. Additional information could markedly change the rankings assigned.

† Inclusion in list not justified on basis of Hearsh Objective.

†† Nominal EI set equal to zero because of inclusion on Integrated Communication Experiment.

preliminary and subject to some rather significant caveats, as noted in Section III.

With these qualifications in mind regarding the validity of the derived payload importance levels, however, SRI has proceeded to exercise the techniques outlined in this section to rank-order three payloads identified by Fairchild in Reference 3. The components of these payloads are listed in Table 6 as is the weight for each experiment, as taken from Table 5. In computing the value of PI for these experiments, SRI made the following assumptions:

- (1) In the absence of information on the financial capability of potential sponsors, the Time-Phasing factor (TP) is set equal to unity for all three payloads.
- (2) It is assumed that the three payloads do not exceed the (large) spacecraft's capacity in any way. Thus, SRI has set TC equal to unity for all three payloads.
- (3) For simplicity, each payload is treated as if no previous payload had been selected. Thus, SRI has set $ND_i = 1$ for each experiment if it is not duplicated within a given payload.
- (4) It is assumed that the only test required for the computation of EC is to determine if the optimizing, supporting instruments for each experiment are included in the payload being considered.
- (5) The Spacecraft Utility factor (SU) is defined as unity for Payloads No. 2 and 3, but is set equal to $(740/797) = 0.93$ for Payload No. 1. This value for Payload No. 1 is the ratio of the weight of the experiments on Payload No. 1 to that of those on Payload No. 2. This assignment of SU values appears reasonable in view of the observation that:
 - (a) Payloads No. 1 and No. 2 differ only in that No. 2 includes two additional experiments and, therefore, more nearly utilizes the total spacecraft capacity.
 - (b) Payloads No. 2 and No. 3 appear to make nearly maximum utility of the (large) spacecraft capacity.*

* This appears to be the case even though Payload No. 2 has a much larger weight in experiments than does No. 3: 797 kg vs 500 kg. However, the spacecraft bus weight required for Payload No. 3 is some 400 kg larger than for No. 2 so that comparable IUS thrust capabilities are needed.

Table 6
CANDIDATE IUS PAYLOADS

Payload Name	Experiment Instrument	Experiment Weight (kg)
No. 1	1.5-m Telescope Radiometer	600
	UHF Data Collection System	40
	Cesium Ion Engine	42
	PATTI	10
	PADS	38
	Fuel Cell	10
No. 2	1.5-m Telescope Radiometer	600
	UHF Data Collection System	40
	Cesium Ion Engine	42
	PATTI	10
	PADS	38
	Fuel Cell	10
	Colliod Ion Engine	34
	Geostationary Laser Reflector	23
No. 3	AASIR (Cloud Physics Radiometer)	96
	UHF Data Collection	40
	Cesium Ion Engine	42
	Colliod Ion Engine	34
	PATTI	10
	Disaster Warning	200
	PADS	38
	Fuel Cell	10
	Geostationary Laser Reflector	23
	High Voltage Solar Array	7

Under the above assumptions, SRI has used the PRIF x Weight values listed in Table 5 to calculate the following values of PI for the three payloads listed in Table 6. The resulting values are 2.22, 2.43, and 2.28 for Payloads No. 1, 2, and 3, respectively.* Thus, of these three payloads, Payload No. 2 is evaluated to be the most important; that is, it has the highest average effective PRIF subject to the caveats given above.

In addition to providing example results of PI for defined payloads, SRI has also exercised, by a hand utilization of the Partial Enumeration Algorithm, the technique to determine an ordered set of the most important IUS payloads consisting of the experiments/instruments identified by Fairchild. This exercise is admittedly of limited usefulness since many of the data needed were not available. However, the attempt demonstrated the feasibility of the method.

In this payload selection process, SRI made the following simplifying assumptions:

- (1) The spacecraft weight capacity was assumed to be 500 kg if the AASIR (equivalent to the Geosynchronous Cloud Physics Radiometer) is a component of the payload; 800 kg, otherwise. This assumption is consistent with the previous assumptions in rating the three payloads defined by Fairchild.
- (2) The factor TP was assumed to be unity.
- (3) The factor EC was calculated considering only intra-payload completeness (see assumption (4) above for the three-payload ranking exercise).

Under these assumptions, SRI used its payload selection technique to identify the following experiments as making up the most important payload possible using only those experiments/instruments from Table 5 for which weights were known to SRI:

* The Disaster Warning System in Payload No. 3 was assigned a value of unity for both I and S. A value of 0.97 for EI was used, consistent with SRI's assignment of the following relevance values for the 37 Hearth Objectives shown in Table 1: 2,2,2,0,1,1,3,1,1,1,1,2,3,3,3,3,1,3,0,0,3,3,0,0,0,0,0,0,0,0,3,0,2,1,1,1,0.

- 1.5-m Telescope Radiometer
- Cesium Ion Engine
- Colloid Ion Engine
- Data Collection System
- Microwave Vertical Atmospheric Sounder
- Fuel Cell

This payload weighs 799 kg and has an importance rating of 2.60. With this as the first, most important payload, SRI found the following experiments make up the next most important payload, subject to the assumptions stated and the limited input data available:

- Integrated Communication Experiment
- Cesium Ion Engine
- Geosynchronous Cloud Physics Radiometer
- Atmospheric X-Ray Emission Detector
- Multibeam Experiment
- Geosynchronous Laser Reflector

The ion engine is included in this payload to optimize the performance of the radiometer. The payload has an importance rating of 2.43.

After identifying these two payloads, SRI observed that the Microwave Vertical Atmospheric Sounder (MVAS) is almost a duplicate of the Microwave Measurement of Temperature and Water Vapor Profiles Experiment that forms part of the Integrated Communication Experiment. Thus, an EI of zero may be appropriate for the former experiment even though it apparently is to cover a different frequency range than the latter. If $EI = 0$ for the MVAS, a different set of payloads results. The most important payload would now consist of:

- 1.5-m Telescope Radiometer
- Cesium Ion Engine
- Colloid Ion Engine
- Data Collection System
- Atmospheric X-Ray Emission Detector
- Fuel Cell
- Geosynchronous Laser Reflector.

In this payload, the MVAS is replaced by two experiments from the second payload because the weight of the Integrated Communication Experiment prohibits its inclusion. This payload has an importance rating of 2.47. In this case, the next most important payload was found to have an importance rating of 2.25 and consisted of: .

- Integrated Communication Experiment
- Cesium Ion Engine .
- Geosynchronous Cloud Physics Radiometer
- Multibeam Experiment
- CO₂ Laser Data Relay Experiment
- High Voltage Solar Array Experiment
- PATTI.

The payloads identified above must be viewed only as representative, high-importance payloads until additional data are made available to permit explicit consideration of all candidate experiments and the assignment of more realistic "partial importances." However, they do represent a first-order approximation to the two most important payloads in an ordered set, and the exercise to determine these payloads has demonstrated the feasibility of applying the techniques developed by SRI.

V FUNDING AND COST-SHARING APPROACHES

A. INTRODUCTION

Although interest in recovering the costs of services provided by government to private beneficiaries is recent, its origins are rooted in the User Charge Statute of 1951. This statute provided that, wherever an agency conferred a benefit on a private group, the activity should be self-supporting. This statute also authorized agencies to implement user charges taking into account: (1) direct and indirect costs, (2) value to the recipient, (3) the public policy or interest served, and (4) other pertinent facts. In 1965, President Johnson presented the government's policy on user charges by formally stating that, although the government should not make a profit, it should recover its costs for these beneficial services.

NASA has, of course, had formal cost-sharing or user charge policies for some time, particularly with regard to launch services. Prior to 1973, launch services were priced under a flexible policy in which NASA determined an appropriate price after considering the objectives of the proposed mission and the benefits which might accrue to NASA and the United States. After January 1973, NASA developed a uniform price policy for all domestic organizations other than the U.S. government and foreign or international organizations based on the full cost of a mission, that is, all direct costs and a share of indirect costs associated with the mission. This change in policy as reported in the RAND Recoupment Study¹⁰ significantly increased the cost of launches to potential non-U.S. government users. A comparison of costs is before and after:

	<u>Before</u> (Millions)	<u>After</u> (Millions)
Thor/Delta	\$ 7	\$ 8.6
Atlas Centaur	16	20.0

It is not clear that user charges based on average cost represent either good economics or sound policy for NASA. The Shuttle/Tug Program, approved but still in early development, presents some interesting considerations as far as user charges are concerned. Since the program must rely on users other than NASA/DoD if it is to achieve its economy goals, user charges must both encourage other agencies (government or private) to undertake the marginal* mission but still recover fair and equitable costs. In addition, since the R&D required to fulfill Hearsh objectives will be extensive, early participation in the Shuttle/IUS experimental program through cost sharing is almost mandatory, given NASA's budget constraints. Thus, to the extent possible, NASA must develop a user charge strategy which will encourage early program participation while recovering costs consistent with government policies.

B. EVALUATION CRITERIA AND CANDIDATE FUNDING STRATEGIES

1. General

A rather lengthy analysis of previous detailed studies of alternative user charge strategies, particularly those by the RAND Corp¹⁰ and the Department of Transportation,¹¹ was performed by SRI as a preface to deriving the viable funding strategies for the IUS/Shuttle discussed in this section. This analysis is documented in Appendix D, which presents the rationale used by SRI in (1) developing the criteria for evaluating funding strategies, (2) identifying the most promising candidate strategies, and (3) establishing the need for flexible funding strategies for developing sponsor participation.

2. Summary of Evaluation Criteria and Strategies Considered

The following criteria and strategies form the basis for deriving viable funding strategies in the following section, C.

* The word "marginal" in this section is used in the sense of "next." For example, the "marginal flight" (or "marginal mission") is the next flight being planned to accommodate potential sponsors, within the context that there are other flights already firmly scheduled (in this case, by NASA and the DoD); and marginal pricing and marginal costs refer to the pricing and costs associated with a marginal flight or launch.

a. Evaluation Criteria

The evaluation criteria* include:

- (1) Efficiency - The degree to which the strategy leads to an efficient allocation of resources in terms of gross national product
- (2) Equity - The degree to which the allocation strategy ensures that no user of the system is subsidized by the public as a whole
- (3) Ability and willingness to pay - The degree to which the strategy accounts for the potential user's financial constraints
- (4) Recovery of costs - The ability of the strategy to recover the desired level of cost, and
- (5) Administrative ease - An assessment of the difficulties of administering the strategy.

b. Strategies

The strategies* evaluated include:

- (1) Long-run marginal cost
- (2) Long-run costs
- (3) Short-run marginal cost
- (4) Average (full) cost
- (5) Two-part strategies, and
- (6) Value of service.

The strategies are rated against the criteria in the following matrix:

Strategies	Evaluation Criteria				
	Efficiency	Equity	Pay	Recovery	Administration
Long-Run Marginal	Yes	No	No	No	No
Long-Run	Partial	No	No	Yes	Partial
Short-Run Marginal	Partial	No	No	Yes	Yes
Average	No	No	No	Yes	Yes
Two-Part	Partial	No	No	Yes	Yes
Value of Service	No	Partial	Yes	Yes	No

* Rationale for their selection is presented in Appendix D.

SRI concluded that none of these policies is clearly preferred for all or even most situations facing NASA. This is consistent with the findings of the RAND study,¹⁰ which was conducted at a much greater depth than the budget and time constraints allowed for this analysis.

C. DERIVATION OF VIABLE FUNDING STRATEGIES

Despite the conclusion above, it will be possible to state some guidelines which will assist NASA in developing an appropriate system of user charges. Application of the guidelines requires an understanding of marginal costs and the difference between long- and short-run costs. Marginal costs represent the cost of supplying the next unit of service. In theory, marginal costs can be obtained by differentiating the production function, in this case, the production function for space services. In practice, it is almost impossible to specify the production function so that a true measure of marginal cost can be obtained. Generally, reasonable approximations of marginal costs can be obtained by developing incremental costs from an analysis of all relevant cost elements. A cost element is relevant if its magnitude changes with a change in volume.

The distinction between long- and short-run costs is also important. In the short run, cost elements are assumed to be fixed rather than variable with changes in volume. In the long run all cost elements are variable so that long-run costs include necessary modification of capacities. More specifically, in the short run, money already spent is considered "sunk" and excluded from consideration since the decision at hand cannot change the cost. In the long-run case, sunk costs are considered since the under- or over-utilization of facilities affects the true cost.

Finally, when determining costs to be recovered through user charges, it is important to consider the benefits or disbenefits accruing to the public at large from the particular government activities. Theoretically, long-run marginal costs should be reduced by such benefits and increased to reflect disbenefits (air or noise pollution for example). This factor significantly increases the difficulty of determining marginal costs.

With these factors in mind, it is possible to establish guidelines for developing a flexible user charge system. A two-phased approach is suggested: (1) determine the cost elements to be recovered and (2) develop alternative strategies for their recovery. Since most economists agree that government services should be priced at long-run marginal cost, this factor should be recognized in both determining the cost base and selecting allocation methods. While it is possible that a production function could be developed through research, this process would be expensive with no certainty of reasonable results. Instead, long-run incremental costs can be developed as a proxy for marginals. Short-run costs can be developed from this base by noting which costs are sunk and which are impacted by the marginal flight.

Thus the cost base can be developed so that the distinction between long- and short-run costs can be made. The steps involved are:

- (1) Postulate and quantify all cost elements associated with the programs of interest. For Shuttle/IUS/Tug programs this would include, in the long run:
(a) R&D, procurement, and operating costs associated with payloads; (b) R&D, procurement, and operating costs associated with Shuttle/IUS/Tug; and (c) all relevant costs associated with payloads, launch vehicles, NASA research centers, and NASA management.
- (2) For each element of cost, determine the amount already spent or irrevocably committed and the amount that could be avoided if the programs were cancelled. This, of course, changes with time.
- (3) For each element, determine the amount of the avoidable cost which must be expended to accomplish currently scheduled NASA/DoD missions and the amount of avoidable cost currently designated to accomplish other missions.
- (4) Determine whether costs should be recovered on a long-run or short-run basis.

Conceptually, this last step presents the greatest difficulty because it combines both economic and political considerations. However, the hardest question to answer is whether or not user charges should include Shuttle program R&D costs. In theory, user charges should include these costs if: (1) the benefits to the public at large are judged zero, or (2) if NASA can maintain long-term space technological development only through recovery of Shuttle R&D costs from users.

Currently, one can assume that these conditions do not hold. The Office of Management and Budget (OMB), the Administration, and Congress have approved the Shuttle program. This implies that a judgment has been made that the public benefits of the program outweigh its development costs. However, programs have been cancelled in the past, and NASA must consider whether or not the costs of Shuttle R&D must be recovered to ensure continued funding of this and future programs. Based on the information available, it appears, however, that Shuttle/Tug R&D costs can be excluded from the cost elements to be recovered. On the other hand, since the IUS is expendable, its total cost should be included.

The next major question involves the procurement cost of the Shuttle and Tug. It seems likely that the costs should be amortized over the programmed number of flights. Hardware cost for each flight is likely to be a small percentage of the total cost, and on the assumption that the demand for flights is somewhat insensitive to price, inclusion will not inhibit the marginal flight. On the other hand, one could argue that such costs need not even be included since Congressional approval of the program implies availability of the vehicles necessary to implement the program.

Given that these questions concerning the magnitude of the costs for each element can be resolved, the cost base would thus reflect the desired policy toward pricing according to long-or short-run costs. Average costs can be obtained by dividing the total of the appropriate costs by the total number of missions. Incremental costs, as a proxy for marginals, can be obtained by dividing the total cost of NASA/DOD missions by the number of such missions.

Allocation of cost among users can only be done when those costs common to all users can be allocated on a rational basis. All methods will be arbitrary since there is no method in economic theory for allocating such common costs. Three methods are suggested, each with its own strengths. These are:

- (1) Units of Use - Common costs can be allocated on the basis of capacity required. Capacity can be measured in terms of weight, space, and power required.

- (2) Separate Costs - Common costs can be allocated proportionally to the direct costs associated with each user
- (3) Value of Services - Common costs could be allocated according to benefits derived.

Many cost accounting systems allocate fixed costs (which are a proxy for common costs) by the first two methods. The third method is perhaps preferable but cannot often be used because the value of service to users cannot be clearly defined and stated. Allocating common costs on the basis of units of use is probably the most satisfactory method available.

Thus far the SRI analysis has defined the elements of cost to be developed and ways for assigning common costs. These provide a basis for using the following allocation strategies:

- (1) Long-run costs - It will be valuable to develop long-run incremental costs as a yardstick for comparison even if no costs are actually allocated on this basis. It should be noted that long-run marginal cost will approximate those for the short run if Shuttle R&D costs are excluded and there is only a small impact from the under or over utilization of existing capacities.
- (2) Short-run marginal costs - These costs are readily estimated on an incremental basis and should be the basis for charges to other government agencies. Short-run marginal costs reflect the utilization of resources actually required to achieve the marginal launch.
- (3) Two-part pricing - Two-part pricing strategies may be appropriate as a basis for charges to non-government users. These have the effect of higher than marginal costs for the first units of service with additional units priced at the margin.
- (4) Average cost pricing - Average cost pricing has the advantage of recovering all costs associated with a particular activity. It may be advantageous to use average cost methods in a two-part pricing scheme.

None of these methods is preferred for all or even most applications. Where non-government sponsors are involved, two-part pricing offers an attractive means of encouraging early R&D participation. Those potential

customers who are willing to take some of the early risk could be given a preferred price when the operational system is available.

It is important to note one additional facet affecting user charge strategies. Many, if not most, of the benefits associated with the Hearth Objectives discussed in other sections of this paper are realized only if the potential user chooses to make use of the service (usually information) provided. Any system of user charges is not likely to have a favorable influence on his decision to use the service. In fact, any charge may discourage use and, thus, limit total benefits accruing. This suggests that while participation of other government agencies may be appropriate, attempts to charge ultimate users for service rendered may in one sense be self defeating.

In conclusion, this section has attempted to outline methods leading to user charge strategies which will be appropriate for NASA. Quite clearly, they depart from the idealized approach commonly used by economists. The approach does, however, provide NASA with a means of reflecting the economic realities in its selection of user charge methods and could yield significant advantages over a system relying on any one cost allocation method.

VI SUMMARY AND CONCLUSIONS

SRI has developed a methodology that enables the determination of justified, high-importance IUS payloads. The methodology can be used to subject a list of candidate payloads to a rank-ordering process; or it can be used to identify the experiments and instruments appropriate for inclusion on high-importance IUS payloads. There are three major steps involved in the technique: (1) justification of the experiments that make up an IUS payload, (2) importance ranking of these experiments, and (3) payload selection. In the first of these three steps, experiment justification, candidate IUS experiments are subjected to three tests to determine: the relevance to accepted objectives, the sufficiency of the related benefits, and the relative worth of the experiment when compared to alternative approaches.

In determining the relevance of specific experiments to accepted objectives, only objectives that have generally recognized merit should be used. The Hearth Objectives serve as an initial set of such objectives that can be used in the early exercising of the methodology. These objectives (listed in Appendix B) are likely to change in time, however, and are probably not complete even in their current form; for example, no basic science activity appears justifiable under the Hearth Objectives listed. Thus, a monitoring activity is needed within NASA to determine the timeliness and completeness of the objectives used.

The determination of relevance of the IUS experiments primarily in the R&D stage to accepted objectives could be made without reference to well defined, non-redundant operational systems: one could assign a high relevance rating to a candidate experiment if it is critical to some operational system that supports a given objective, regardless of whether that system is being seriously considered for implementation or not. However, the significance of the results of the relevance test is somewhat vague if this approach is used because the benefit sufficiency

test that follows the relevance test is not really well defined until one specifies the services provided by the operational system. The systems identified by the Hearth Committee were used in this study to provide the needed definition of non-redundant operational systems. The systems identified by the Hearth Committee form a set of non-redundant operational systems supporting the Hearth Objectives. However, the set of experiments/instruments proposed by Fairchild does not correspond very well to the list of instruments identified by the Hearth Committee as requiring additional R&D to field the Hearth operational systems. Some correlation does exist as indicated in Table 1 where a shaded box represents possible utilization of a Fairchild instrument in the operational system proposed by the Hearth Committee for meeting a specific Hearth Objective. The lack of complete correlation, however, means that determination of a full set of appropriate relevance entries is not possible at this time. Therefore, the subsequent analyses performed for the Fairchild instruments serve primarily to illustrate the use of the methodology; the derived importance rankings must be viewed as preliminary until a more complete and consistent data base becomes available.

The second test in the experiment justification step of the methodology is that of determining the sufficiency of benefits arising from the candidate experiment. This test is initially made by comparing the life-cycle costs of the operational system(s) with the benefits that accrue from implementing the system(s), the development of which is supported by the experiment under consideration. If these costs are less than the benefits, the experiment passes the test. If the costs exceed the benefits, then it must be determined if some other benefit (for example, the benefit from basic science experiments) warrants continued consideration of the experiment. In utilizing the results of existing benefit analyses, it was determined that only a few IUS experiments may pass this benefit test without ambiguity. This is due to uncertainties*

* As a result of these uncertainties, the hard, demonstrable cost benefits may be only a fraction of the potential cost benefits that could accrue from an operational system.

in two factors which markedly influence the level of benefits obtainable from implementing a given system: (1) the uncertainty of the extent to which the services provided will actually be utilized by the potential users and (2) the uncertainty of the benefits from a specified level of utilization of the service.

The third and last test in the experiment justification procedure is to determine if, among the alternative approaches to develop the capability to field worthwhile operational systems, the candidate IUS experiment offers the best approach. Early in a development program, the answer to this question may not be known. In this case, competing approaches (experiments) should be retained as justifiable experiments. As soon as the query can be answered without ambiguity, however, the less desirable approaches should be dropped or, at least, assigned a low importance ranking. This tradeoff analysis is one of the most critical operations in the entire methodology.* It was used to identify possibly redundant candidate experiments, which could be eliminated from further consideration.

Following the first step, instrument justification, the methodology then calls for ranking the justified instruments in order of importance. A set of criteria has been identified to effect this ranking. These criteria are: the level of benefits; the number of application (objective) areas benefited; the importance of the objectives supported by the experiment; the criticality of the experiment to the implementation of the pertinent operational system(s); timeliness of the experiment; and special-case criteria such as previous commitments, legislative action, and national prestige.

A technique was developed whereby a quantitative importance level could be assigned to each candidate IUS experiment, consistent with the above criteria. The method consists of: (1) determining "partial importances" related to the level of cost benefits, the timeliness, and the

* In fact, unless similar tradeoff analyses are made at the operational system level, the analysis for IUS experiments could be somewhat academic. That is, the operational systems used in the IUS analysis should first have been shown to represent reasonable, if not the best, operational systems for supporting the objectives.

criticality of the experiment, as well as the importance of each relevant objective; (2) multiplying these partial importances together for a given objective; and (3) then, summing over all objectives benefited by the experiment. Table 4 shows the results of applying the method to the Fairchild set of experiments/instruments using the entries in Table 1 as a measure of the criticality of each experiment. The resulting importance ratings should be viewed with the following caveats, however.

- (1) The level-of-benefits "partial importance" parameter was set equal to unity for all experiments. It was not possible to calculate the parameter for each experiment because the operational systems for the list of instruments have not been adequately defined. Thus, subsequent analysis with more complete data will reduce the importance ratings of many of the experiments listed in Table 4.
- (2) The ratings in Table 4 were derived using the relevance (criticality) factors shown in Table 1. The entries in Table 1, however, must be considered preliminary until the operational systems corresponding to the experiments/instruments are well defined. When these operational systems are defined, a new table can be constructed which will reflect realistic estimates of the experiment/instrument criticality. Some new entries will be added, and the criticality ratings of existing entries will probably be modified either upward or downward.
- (3) The timeliness factor used in this rating exercise was also set equal to unity in deriving the ratings shown in Table 4 because the operational systems and their implementation schedules were not defined. However, more appropriate values can be determined when valid data are available.
- (4) None of the Special Criteria were applied in determining the importance ratings in Table 4 and only the Hearth Objectives identified in Appendix B of the main report were used to define the application areas considered. Consequently, the application of special criteria will also influence the ratings given in this study.

Although the rankings shown in Table 4 should be considered preliminary, the method developed in the study has been shown to be feasible in application and to yield appropriate importance rankings based on the

preliminary input data available and the criteria identified. A conclusive rank ordering, however, will depend upon provision of accurate and complete input data.

The third and final step of the methodology consists of formally selecting high-priority IUS payloads. A set of eight criteria was developed and illustratively exercised to rank order previously defined payloads and to select the experiments for a high-priority payload:

- (1) Technical Compatibility: The payload must observe the weight, volume, and power constraints of the spacecraft.
- (2) Non-Duplication: Experiments should not be duplicated needlessly on an IUS flight.
- (3) Experiment Importance: Preference should be given to experiments rated high in importance in the second step of the methodology.
- (4) Experiment Completeness: If a decision is made to fly an experiment critically needed for an operational system, all experiments needed for that system should be flown.
- (5) Sponsorship: Preference should be given to experiments for which non-NASA funding sources are most probable.
- (6) Time-Phasing: One should time-phase those experiments to be sponsored by a given sponsor to match his budgetary constraints.
- (7) Immediacy: Preference in IUS payloads should be given to experiments that support rapid deployment of operational systems.
- (8) Spacecraft Utility: Every attempt should be made to make full utilization of the spacecraft capacity on each flight.

A quantitative measure of importance for IUS payloads has been defined by SRI consistent with the above eight criteria. This measure has been used to rank order selected IUS payloads proposed by Fairchild.

The payload importance function was used to construct a method for selecting IUS payloads in decreasing order of importance where each payload selected is the most important of all possible IUS payloads for a specified spacecraft capability and list of candidate experiments, given

the selection of the previous more important payloads. The selection process reduces to a problem in non-linear programming where each experiment has associated with it a variable that takes on the value 0 or 1, depending upon whether that experiment is present or absent from the payload. An algorithm exists to perform this selection process without having to examine all possible payloads.

Various cost-sharing strategies were assessed for IUS missions. These included: long-run marginal cost, long-run costs, short-run marginal cost, average (full) cost, two-part pricing, and value-of-service strategies. Each strategy was rated against five criteria: efficiency, equity, sponsor's ability to pay, recovery of costs, and administrative ease. No one strategy was found to offer a clear-cut advantage over the others for all potential sponsors. Thus, in view of the fact that the best strategy may vary from one sponsor to another, it is suggested that NASA maintain a flexible strategy within the constraints imposed by Congress or other agencies of the government.

Particular advantages were found for using a short-run marginal cost approach for other government agencies and for two-part pricing strategies for non-government users. However, in many (if not most) cases, no strategy will either enhance NASA's ability to attract early participation or encourage the marginal (next) mission. In addition, it was recognized that formal attempts to implement cost-sharing strategies may actually inhibit the realization of potential benefits from an operational system by unfavorably influencing a potential user on his decision to use the service. Thus, while participation by other government agencies may be appropriate, attempts to charge ultimate users for service may be partially self defeating.

The study findings as summarized above support the following major conclusions:

- (1) An adequate methodology for selecting justified, high-priority IUS payloads has been developed. However, the users of the methodology should recognize that:
 - (a) Accepted objectives must be continually monitored and updated as needed.

- (b) Justification of many experiments may have to be made on the basis of potential rather than hard, demonstrable cost benefits or on bases other than cost benefits.
 - (c) The high importance assigned to the IUS instruments and payloads selected by the methodology is dependent upon identifying operational systems that have, themselves, been shown to be the "best" among alternatives.
 - (d) Although techniques have been developed (i) to rank order candidate IUS experiments/instruments and previously defined IUS payloads and (ii) to identify the most important IUS payloads in order of decreasing importance, each represents only one possible method (albeit a reasonable one) whereby one can systematically assign a quantitative value to the "importance" of an experiment or payload.
 - (e) The appropriateness of the formulas for assigning quantitative importance rankings must be operationally tested because they essentially represent attempts to measure objectively values that are predominately subjective.
- (2) NASA should maintain flexibility in its funding strategies because of differences among potential sponsors and because of possible changes in governmental policy related to setting user charges. Charging policies appropriate for governmental and non-governmental sponsors were identified.

In view of the above observations, SRI recommends that the following steps be taken:

- (1) A compatible set of experiments and operational systems should be identified.
- (2) The Hearth Objectives should be expanded to include space and basic science objectives, if this has not already been done.
- (3) The various costs associated with the candidate payloads and experiments should be identified to provide the data base needed for NASA to determine the actual costs for a flexible pricing strategy. These data are needed because many potential sponsors are on four-year or longer budget cycles, and rather firm pricing data are needed quickly to enhance the possibilities of enlisting these sponsors for IUS flights.

REFERENCES

1. J. L. Archer, N. A. Beauchamp, D. C. MacMichael, "Development of Methodologies and Procedures for Identifying STS Users and Uses, Contract No. NAS8-30533, SRI-Huntsville, (June 20, 1974)
2. J. L. Archer and N. A. Beauchamp, "User Community Development for the Space Transportation System/Spacelab," Contract No. NAS8-30533 (October 1974)
3. "Shuttle/IUS Payload Definition Presentations to GSFC," Fairchild Space and Electronics Company (March 20, 1975)
4. The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service, Part I (December 20, 1974), Part II (October 31, 1974), and Part III (December 20, 1974) of Volume III "Intensive Use of Living Resources: Agriculture," ECON Incorporated
5. "An Analysis of the Benefits and Costs of an Improved Crop Acreage Forecasting System Utilizing Earth Resources Satellite or Aircraft Information," Earth Satellite Corporation (November 16, 1973)
6. "Some Economic Benefits of a Synchronous Earth Observatory Satellite," Executive Summary (NASA CR-ERIM 107400-4-X) and Final Report (NASA CR-ERIM 107400-4-F), Environmental Research Institute of Michigan and ECON Incorporated (September 1974)
7. "Evaluation of Economic, Environmental and Social Costs and Benefits of Future Earth Resources Survey Satellite Systems," Second Quarterly Progress Report May-July 1973, Earth Satellite Corporation (August 10, 1973)
8. "Economic Viability of the Proposed United States Communications Satellite System," Final Report on SRI Project 1441 (October 1971)
9. H. M. Wagner, Principles of Operations Research with Applications to Managerial Decisions, Prentice-Hall, Englewood Cliffs, N. J., (1969), pp. 486 to 488.
10. "Pricing and Recoupment Policies for Commercially Useful Technology Resulting from NASA Programs," R-1671-NASA, RAND (January 1975)
11. "Allocation of Airport and Airways System Costs," Working Paper Number 10, Aviation Cost Allocation Study, Department of Transportation (December 1972)

APPENDIX A

LETTER FROM MR. ANDERSON TO MR. FLETCHER

Appendix A

LETTER FROM MR. ANDERSON TO MR. FLETCHER

On July 29, 1974, Mr. James C. Fletcher, Administrator of NASA, sent letters to various research groups requesting inputs to "a comprehensive long-range study, 'Outlook for Space,' which will explore the role of space exploration and the peaceful uses of space in the 1980 to 2000 time frame." Mr. Charles A. Anderson, the President of Stanford Research Institute (SRI), framed SRI's response in a letter of August 12, 1974, reproduced on the following pages. It is felt that the thoughts presented are shared by many members of both the public and private sectors of this country, as illustrated by the Hearth Committee findings (summarized in Appendix B) and interviews conducted by SRI with potential government users in another Shuttle related study.^{A-1*}

* Superscript numbers denote references at the end of this Appendix.

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STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA 94025
(415) 326-6200

CHARLES A. ANDERSON
President and Chief Executive Officer

Dear Mr. Fletcher:

Your letter of July 29 concerning the "Outlook for Space" poses some very interesting and also very difficult questions. I have asked a number of my SRI associates to contribute their thinking on the subject and this letter indicates some of their views, which I hope might be useful.

It is fairly easy to identify a list of things for which space exploration or space operations can be used. There have been so many possible uses or roles of space already identified that it is difficult to add to that basic list. Table I shows the various program application areas for which NASA might consider supporting space endeavors. The various classes of missions that might be applicable to each basic programmatic objective are also shown. We feel that a more complete identification than shown in the table of the specific relationships between space missions and program applications can be helpful in the planning.

Rather than possible use of space, the more important and certainly the more difficult question is what can, feasibly, be done in space considering the real constraints that are going to exist in the 1980 to 2000 time period. The results obtained from the space exploration must be examined to see if and how they can provide a better basis for both national and international legislation for the proper, sensible management of the available continental and marine resources of this planet.

Under contract to Marshall Space Flight Center, NASA Contract No. NAS8-30533, SRI is currently involved in a form of such an activity looking at methods for identifying users for the space shuttle. The question, as it is addressed in this case, is not so much what can be done, but what should be done. In the following paragraphs we present some of our thoughts developed during the conduct of the study.

It appears very unlikely to us that there will be a change in the basic attitudes or priorities in this country during the 1980 to 2000 time frame to permit large amounts of money to be spent for space spectacles

Mr. James C. Fletcher

or space endeavors for purely scientific purposes. In order to obtain support, programs in that time period must be structured to improve or maintain the qualities of life. However, some purely scientific endeavors can and should be included. It is already clear that some of the basic and overriding problems of mankind in the two decades being considered will be shortages of energy and other raw materials, water, food and the degradation of the world environment. We feel these problems will determine what is done in those decades since failure to address them will endanger the quality of life of man. Thus, we believe, the primary endeavors of NASA should be directed toward these areas. We do caution, however, that needs and priorities may change drastically during the time period, so the NASA program must be structured to maintain a degree of flexibility and must be reevaluated continually to consider changing needs.

The endeavors to be done in space should be selected considering the present roles and needs, as well as the long-term future needs and requirements. This must be done in conjunction with the various other departments of the Federal Government which minister to these needs and with state and local governments which are dealing with problems at the "grass roots" level. These federal agencies would include: the Federal Energy Administration in developing or identifying specific needs in the exploration, exploitation, or conservation of energy which can be done via space endeavors; the Department of Agriculture for those things which could affect this country's and the world's food supplies; the Department of the Interior for activities concerning resources including our water supply; the Atomic Energy Commission; the Department of Commerce; and the suggested new ERDA if it is initiated. All states should be included and local governments can be served through the states.

We suggest that NASA, armed with the knowledge of what can be done in space, then seek partnerships with the various institutional portions of the Federal Government and state governments that represent the various needs of man and attempt to work with the appropriate organizations to develop space endeavors which can favorably impact the quality of life not only in the two decades being considered, but far into the future.

In this manner the program of NASA can be built on identified needs and be established in conjunction with those institutional entities that will serve as the intermediate and end user of space services as the results are channeled to the public sector. It would also be wise to coordinate with certain large industries and selected industry representatives to identify areas where manufacturing in space may be needed; but starting from the consideration of contribution of the product rather than just from the existence of capability in NASA.

Two additional areas that we feel should be explored are long-range weather forecasting and, one that is far less clear from an institutional

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responsibility standpoint, that of climatic control or modification. It appears that the world may be in a period of climatic change. The drought and temperature changes in this country and in other parts of the world bear this out. Whether this is a long-term change or a transient change of some short period, we do not know and have as yet no real means of determining.

Already the change in climate has had impact on the world's food supplies at a time when more and more food is needed. If this is a long-term change that may become worse, it is going to exacerbate an already critical world food problem. NASA, in conjunction with NOAA, might consider a program to develop sufficient understanding of specific geographical climatic conditions, and what causes these conditions, to develop means of predicting and someday modifying them. Some work is going on in this area now, but not on a scale necessary for modifying worldwide weather conditions. Prior to any global modification considerations, however, a much better understanding on a smaller scale, specific to local geographical situations must be achieved. Once the details of these smaller-scale situations are understood, then and only then, will it be possible to tackle global problems. It appears to us that the only plausible way that either the smaller-scale or the large-scale manipulation of climate could ever be done is from space. Extremely large amounts of energy will have to be used to make any significant modification to the world's weather on a global basis, or even on a specific geographical smaller-scale basis. The only source of such energy is extraterrestrial. We do not know that worldwide weather manipulation is feasible; and certainly it is a long-term project. However, it is something that is worthy of consideration.

The outlook for NASA need not, and should not be totally oriented toward projects directly related to the quality of life, but the program should be dominated by these types of projects. Together with this main theme long-term scientific endeavors should be initiated for furthering knowledge of the universe in areas that can only be done from space. This latter goal should be a secondary goal and structured so that it can be added at a lower level of priorities to more directly related quality-of-life space endeavors.

We would like the opportunity to discuss these and other of our views with you and to present in more detail the results and ideas we have assembled in past and present work for NASA and other federal agencies.

You have suggested that a senior member of our staff be designated to serve as liaison with your study group under Mr. Hearsh's direction. I have designated Dr. Ernest J. Moore, Vice President of Research Operations, to serve in this role for SRI. Dr. Moore can bring together the

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several resources of our organization that have appropriate capabilities and interests in this subject and I hope you will call on him.

Sincerely,

Charles A. Anderson

cc: Mr. Donald P. Heath

Attachment: Table 1

Table A-1
SPACE MISSION CATEGORIES

PROGRAM APPLICATION	MONITORING SATELLITES	SPACE STATION	LUNAR BASE	ASTEROID AND COMET MISSIONS	PLANETARY MISSIONS	SOLAR MISSIONS	STELLAR OBSERVATIONS
EARTH RESOURCES							
• ENERGY	X	X				X	X
• WATER	X	X					
• FOOD	X	X					
• RAW MATERIALS		X	X		?		
EARTH PHENOMENA							
• LAND							
• VOLCANIC ACTIVITY	X	X	X		X		
• EARTHQUAKES	X	X	X		X		
• TEMPERATURE CHANGES	X	X	X		X	X	
• MOISTURE CHANGES	X	X					
• WATER							
• OCEAN DYNAMICS	X	X					
• LIMNOLOGY	X	X					
• MOISTURE PATTERNS	X	X					
• ATMOSPHERE							
• ATMOSPHERE DYNAMICS	X	X			X	?	?
• CLIMATOLOGY	X	X			X	?	
• CLOUD DYNAMICS	X	X			X	?	
• WEATHER STRUCTURES	X	X			X		
CIVILIZATION PHENOMENA							
• ENVIRONMENTAL CONTROL AND MONITORING	X	X			X?		
• CLEAN BIOSPHERE	✓	✓					
• WEATHER CONTROL		✓			✓		
• MANUFACTURING		X	X		?		
• COMMUNICATIONS/NAVIGATION	X	X					
• POWER GENERATION	X	X				X?	
• OPERATIONS CONTROL	X	X					
• TRANSPORTATION	✓	✓					
• POPULATION	✓	✓					
PHYSICAL SCIENCES							
• PHYSICS	X	X	X	X		X	X
• ASTRONOMY	X	X		X		X	X
• METEOROLOGY	X	X		?		?	?
• GEOLOGY	X	X	X	?		?	?
• PLANETOLOGY	X	X	X	?		?	?
BIOLOGICAL SCIENCES							
• MEDICINE	X	X	X				
• BIOLOGY	X	X	X				
• BOTANY AND AGRICULTURE	X	X	X				
• EXOBIOLOGY				?	X		?

LEGEND

- X RELEVANT GENERAL PROBLEM
- ✓ RELEVANT SPECIAL PROBLEM
- ? RELEVANCE UNCERTAIN

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REFERENCE

- A-1. J. L. Archer, N. A. Beauchamp, and D. C. MacMichael, Appendix B to "Development of Methodologies and Procedures for Identifying STS Users and Uses," Contract No. NAS8-30533, SRI-Huntsville, (June 20, 1974)

APPENDIX B

SUMMARY OF THE HEARTH COMMITTEE STUDY
ON THE "OUTLOOK FOR SPACE"

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Appendix B
SUMMARY OF THE HEARTH COMMITTEE STUDY
ON THE "OUTLOOK FOR SPACE"

1. GENERAL

A significant effort to identify new directions for future space activities in terms of real purpose and value to the U.S. has been conducted by the Hearth Committee.* The results of this effort were expressed in terms of 8 themes which are supported by 37 specific objectives.

These themes form a framework within which to establish space goals and priorities for a broad range of quality of life issues as well as a spectrum of problems of national importance and interest which are not normally regarded in the context of space activities. These eight themes are:

- | | |
|---|--------|
| (1) Production of Food and Forestry Resources | (01)** |
| (2) Prediction and Protection of the Environment | (02) |
| (3) Protection of Life and Property | (03) |
| (4) Energy and Mineral Exploration | (04) |
| (5) Transfer of Information | (05) |
| (6) Use of Space for Scientific and Commercial Purposes | (06) |
| (7) Improve the Quality and Availability of Health Care | (07) |
| (8) Earth Science | (08) |

The decision to proceed with the development of the Space Transportation System tends to economically support these themes which provide new options and practical benefits for addressing our national needs.

* A committee chaired by Mr. Donald Hearth which was appointed by NASA Administrator Dr. James Eletcher to investigate viable program goals for the use of space.

** The numbers in parenthesis will be used later to correlate specific objectives with the Hearth themes.

2. SUMMARY OF HEARTH COMMITTEE THEMES

In this appendix each theme specified by the Hearth Committee will be summarized and examined in terms of its objective, which in turn will be related to a set of operational systems required to meet the objectives over the next 25 years. In addition, critical instruments, and associated spacecraft characteristics will be identified and related to each objective where specified by the Hearth Committee.

a. Production and Management of Food and Forestry Resources (Theme 01)

The increases in world population and projections for future world population indicate a greater demand for food, water, and other resources than the world has ever known. These demands are occurring at a time when concern for the quality of life is also increasing. It is vital that improvements be made in "production and management of food and forestry resources" without adversely affecting our quality of life. This is the goal of Theme 01. The objectives* given by the Hearth Committee to support this goal are listed in Table B-1.

Among the instruments required to meet the objectives of this theme are advanced multispectral scanners and microwave sensors. These instruments are critical components of spacecraft for use in operational systems designed to meet these objectives. Table B-2 relates the operational systems, spacecraft characteristics, and instruments required for accomplishing the objectives of this theme. The Earth Observation Satellite (EOS) is a basic satellite needed to promote an increase in global crop production (Objective 011) and will be part of the operational systems of all other Theme 01 objectives (Table B-1). As indicated, satellites equipped with microwave sensors (L and X band) will also be required. To predict water availability (Objective 012), the Tiros 0 satellite will be employed along with EOS designated to support Objective 011.

* Note that the objectives for Theme 01 are sequentially numbered to reflect their relationship to the theme: 011, 012, 013, etc. Objectives which appear for other themes will be similarly numbered in accordance with the Hearth report.

Table B-1

THEME 01: PRODUCTION AND MANAGEMENT
OF FOOD AND FORESTRY RESOURCES

Objective	Basic Purpose
011 - Global Crop Production	Provide a biweekly forecast of the global production of major crops having world-wide and/or economic significance
012 - Water Availability	Provide forecasts of water availability for irrigation, hydroelectric power generation and shale cracking based on satellite surveys of snow and moisture
013 - Land Use and Environmental Assessment	Provide surface cover information and application techniques to support land use planning, environmental assessment and monitoring, and natural resource management
014 - Living Marine Resource Assessment	Provide a living marine resource assessment and management system for one or more presently utilized coastal species in the U.S.
015 - Timber Inventory	Develop and implement a capability to inventory the timber of the nation's forests on a five-year cycle with yearly updates based on multistage sampling techniques using satellites and aircraft
016 - Rangeland Assessment	Provide timely assessment of range conditions to support efficient cattle management

Table B-2

THEME 01: PRODUCTION & MANAGEMENT OF FOOD & FORESTRY RESOURCES

Objective	Operational System and Deployment Date	Satellite Weight Class, lb	Number of Satellites Per Operational System	Critical Instruments	Required Resolution, m	Required Orbits and Altitudes, nmi
011 Global Crop Production	I* (Global Wheat Yield) 1982	2500	2 to 6	Multispectral Scanner (MSS)	30	500 Near Polar
	II (Global Crop Yield) 1990	3000	2 to 6	MSS and Microwave Sensor	10	500 Near Polar
	III (All Weather System) 2000	3900	2	Active Microwave Sensors	NA**	NA
012 Water Availability	I (Snow Cover) 1982	2500	2 to 6	MSS	30	500 Near Polar
	II (Moisture) 1990	4000	2 to 6	Microwave Sensors (Dual L & X Band)	NA	500 Near Polar
	III (Continental) 2000	NA	NA	NA	NA	NA
013 Land Use & Environmental Assessment	I (Land Use I) 1982	2500	2 to 6	MSS	30	500 Near Polar
	II (Land Use II)	3000	2 to 6	MSS	30	500 Near Polar
014 Living Marine Resources Assessment	I (Coastal Species) 2000	4000	2 to 4	Microwave Sensor and Scanning Laser Spectrometer	50 for Coastal (0.1 to 1 km Ocean)	500 Near Polar
015 Timber Inventory	I (Timber I) 1982	2500	2 to 6	MSS	30	500 Near Polar
	II (Timber II) 1990	3000	2 to 6	MSS and Microwave Sensor	10	500 Near Polar
016 Range Land Assessment	I (Range I) 1982	2500	2 to 6	MSS	30	500 Near Polar
	II (Range II) 1989	3000	2 to 6	MSS	10	500 Near Polar
	III (Range III) 1999	3900	2	Active Microwave Sensors	NA	

* The Roman numerals refer to sequential operational systems fielded to accomplish each objective.

** Not available.

b. Prediction and Protection of the Environment (Theme 02)

The U.S. and world economies depend greatly on weather, because weather and climatic changes affect not only agricultural yields of food, planning, and management of food and energy resources, but the planning and management of many other industries, for example, the construction, transportation, and recreation industries. Improved capabilities in predicting weather and climatic changes and perhaps even controlling them would have a favorable impact on the overall quality of life. The objectives which support this important thematic area are listed in Table B-3.

These objectives can be met by the operational systems shown in Table B-4. These consist of a series of satellites in near-earth (Tiros-0), sunsynchronous, and geosynchronous orbits. These satellites are designed to measure and observe weather phenomena, sea temperatures, air temperatures, humidity, the effects of solar radiation on general atmospheric circulation, characteristics of snow and ice packs, various hydrological parameters, and atmospheric components including CO₂, ozone, and aerosols. Spacecraft like the Tiros 0 satellite and advanced versions of the NIMBUS G satellite will play an important role in meeting these objectives.

Table B-4 relates the operational systems, spacecraft characteristics, and critical instruments required for meeting the Theme 02 objectives.

c. Protection of Life and Property (Theme 03)

The loss of life and property due to severe storms, atmospheric pollution, floods, fires, and other hazards are intensified by inadequate detection and communication of these threats. These tragedies and hardships on both individuals and companies could be prevented or reduced by the use of space for protecting life and property. Table B-5 lists the objectives for this theme.

The operational system used to support Objective 031 will initially include the weather satellite SMS/GOES developed for Objective 021 (Table B-4). Subsequently STORMSAT and the synchronous earth observation satellite (SEOS) would be used. This latter satellite also supports

Table B-3

THEME 02: PREDICTION AND PROTECTION OF THE ENVIRONMENT

Objective	Basic Purpose
021 - Large Scale Weather	Improve accuracy and extend range of weather forecasting of large general atmospheric circulation
022 - Weather Modification	Support the development of a weather modification capability
023 - Climate	Provide the predictability of climate on various time scales and develop seasonal and longer period forecasting capability
024 - Stratospheric Changes and Effects	Identify and monitor those acts of man which may cause changes in the stratosphere and assess their impact
025 - Water Quality	Provide a capability for the use of satellites techniques for water quality evaluation and management
026 - Global Marine Weather	Provide a global marine weather forecasting capability for support of maritime activities

Table B-4

THEME 02: PREDICTION AND PROTECTION OF THE ENVIRONMENT

Objective	Operational System and Deployment Date	Satellite Weight Class, lb	No. of Satellites Per Operational System	Critical Instruments	Required Resolution or Accuracy	Required Orbits
021 Large Scale Weather	I* (Satellites and Free-Floating Balloons) 1985	900	2 to 4	High Resolution Radiometer Small Cloud Physics Radiometer		Near Earth
		NA**	NA			Sun Synchronous
	II 1993	NA	3	Visible & IR Spinscan Radiometer (VISSR) + Atmosphere Sounder = VAS • Active IR Sensors • Multifrequency Doppler System • Active Sounders	NA	Geosynchronous
			4			Near Earth
			1			Sun Synchronous
			3			Geosynchronous
022 Weather Modification	Same as for Objectives 021 and 031	See Objectives 021 and 031				
023 Climate (Long Term Forecasting)	I (Climate I) Includes Systems for Objectives 012, 021, 026, 031, 024, and 033 1980's	NA	6 to 8	• 4 Channel Passive Radiometer • Visible Radiometer • IR Radiometer • Imaging Device	• 500 km for Radiation Measurements • 100 km for Cloud Cover	Low Earth Polar
	II (Climate II) 1980's		6 to 8	• 10 Channel Passive Radiometer	• 500 km for Radiation Measurements • 100 km for Cloud Cover	Low Earth Polar
024 Stratospheric Changes & Effects	R&D Early 1980's		1 (?)	Lower Atmosphere Composition & Temperature = Lactate	NA	NA
	I Early 1985	2000 to 3000	2 to 4	Lower Atmosphere Composition & Temperature = Lactate		
	II 1993	NA	4	High Resolution Laser Radar for Vertical Profile of Aerosol Distribut		
025 Water Availability	(Includes Systems for Objectives 012, 031, 011 and 033) 1982-2000	See Objectives 011, 012, 031, and 033				
026 Global Marine Weather	I 1985	NA	4	• Radar Altimeter • Microwave Radiometer • Scatterometer • Imaging Radar	±10 cm (Land) ±100 cm (Sea) ±20% (Wind Velocity) ±1° C (Sea temp)	Near Polar
	II 1985		4	(Improvements)	(1/2 to 1/10 of above values)	Near Polar (?)

* The Roman numerals refer to sequential operational systems fielded to accomplish each objective.

** Not available.

Table B-5

THEME 03: PROTECTION OF LIFE AND PROPERTY

Objective	Basic Purpose
031 - Local Weather and Severe Storm	Increase the detail and improve the certainty of forecasts of local weather and mesoscale phenomena (e.g., severe storms)
032 - Tropospheric Pollutants	Develop a capability for monitoring tropospheric pollutants to support environmental quality enhancement programs
033 - Hazard Warnings	Provide hazard warning (floods, fires, etc.) based on in-situ measurements relayed through satellites to prediction centers
034 - Communication-Navigation	Implement a world-wide satellite communication-navigation capability

Themes 01 and 02, that is, production and development of food and forestry resources, and prediction and protection of the environment. Table B-6 summarizes the operational systems, spacecraft characteristics, and critical instruments required for accomplishing each objective under Theme 03.

d. Energy and Mineral Exploration (Theme 04)

Known and forecast resources of fossil fuels and minerals are insufficient to meet predicted world-wide demands. Therefore, there is a critical need to locate new fossil fuel and mineral sources, investigate alternative energy sources, and develop the viable alternatives. Space-based programs can contribute to these activities under the Theme 04 objectives listed in Table B-7.

Some research and development for the operational systems needed to support the first three objectives can be carried out using the STS. Fielding of economically viable operational systems will probably require a lower cost launch capability (Studies are continuing to better define these requirements).

The fourth objective, developing a World Geologic Atlas, can be economically achieved using the EOS which is also to be used for Objective 011 (global crop production).

e. Transfer of Information (Theme 05)

There is a growing need and demand for communication services to the American public, the industrialized world, the developing countries, and the underdeveloped countries. This communication need exists for a multitude of services including medicine and education. Table B-8 lists the objectives under this theme.

Communication satellites like DOMSAT and INTELSAT will certainly support the objectives of this theme; but other automated satellites as well as Shuttle sortie missions using Spacelab may be required to develop new and novel communication capabilities for such things as electronic mail systems and computer-to-computer networks.

Table B-6

THEME 03: PROTECTION OF LIFE AND PROPERTY

Objective	Operational System and Deployment Date	Satellite Weight Class, lb	No. of Satellites Per Operational System	Critical Instruments	Resolution	Required Orbits
031 Local Weather & Severe Storm	I* (1985)	740	2 to 3	Advanced Atmosphere Sounding & Image Radiometer (AASIR) (40 cm Optics)	Visual = 7.5 km IR = 4.5 km Sounding = 13.5 km	Geosynchronous
	II (1993)	NA**	2 to 3	Improved AASIR (150 cm Optics)	0.8 km	Geosynchronous
032 Troposphere Pollutants	R & D	NA	1 (?)	NA	NA	Same as Shuttle Sortie
	I (1990)	NA	2 to 4	SO ₂ and NO ₂ Measurements	NA	(60°)
	II (1990) >	NA	2 to 4	<ul style="list-style-type: none"> Passive IR Heterodyne Radiometer Laser Absorption Spectrometer 	NA	(60°)
033 Hazard Warnings	I (Hazard Warning Data Relay) (1985)	1100	4	3 Meter X Band Antenna Laser Antenna Low Gain UHF Antennas	NA	Polar (600 nmi)
		2200	1		NA	Geosynchronous
	II (Improved System I) (2000)	NA	May Be Same As Above	NA	NA	NA
034 Communications & Navigations	I (1985)	NA	3-4 (plus 24 DoD Satellites)	Commun. Beacons	NA	Geosynchronous
	II (1993)	NA	3-4 (?) (plus 24 DoD Satellites)	Commun. Beacons	NA	Geosynchronous
	III (2000)	NA	3	Short Baseline Interferometer	NA	Geosynchronous

* The Roman numerals refer to sequential operational systems fielded to accomplish each objective.

** Not available.

Table B-7

THEME 04: ENERGY AND MINERAL EXPLORATION

Objective	Basic Purpose
041 - Solar Power	Develop a solar power station(s) to provide a significant portion of the nation's energy needs.
042 - Power Relay	Develop a capability to relay large amounts of power over long distances via satellite relay
043 - Hazardous Waste Disposal	Develop and implement a capability of dispose of large quantities of hazardous waste outside the solar system
044 - World Geologic Atlas	Provide a world geologic Atlas to support mineral exploration and development planning

Table B-8

THEME 05: TRANSFER OF INFORMATION

Objective	Basic Purpose
051 - Domestic Communications	Provide a domestic communication satellite network capable of providing the growing information transfer and service requirement of the 1990's
052 - Intercontinental Communications	Provide an intercontinental communications satellite network capability to provide for the increasing information transfer needs of the 1990's

f. Use of Environment of Space for Scientific and Commercial Purposes (Theme 06)

Results from Skylab experiments indicate that environmental factors of space, such as low gravity, can provide new tools for experiments which cannot be duplicated on earth. Table B-9 lists the objectives which support Theme 06.

Unlike those of other themes, the Theme 06 objectives require the use of Spacelab and possibly a space station. Each objective will require special facilities and resources for conducting the experiments and performing specialized functions.

g. Improve the Quality and Availability of Health Care (Theme 07)

Only two objectives have been identified thus far for this theme. These are listed in Table B-10.

Studies of the physiological and disease process like the objectives of Theme 06 (Objective 071) require the Spacelab and a space station to utilize the low gravity environment. It is expected that Spacelab flights required for Objectives 064, 065, and 066 (see Table B-9) may be used to carry appropriate medical and physiological research equipment to accomplish this objective.

Insect-borne diseases plague much of mankind and result in death, human misery, and world-wide food crop losses. EOS, which is to be used for accomplishing Objective 011 (see Table B-1), can also be used to detect disease carrying insects (Objective 072). In addition, the operational systems shown for Objectives 012, 021, 023, and 033 in Tables B-2, B-4, and B-6 may also be used to support Objective 072.

h. Earth Science (Theme 08)

The requirement to better understand the nature of our planet and its continuing evolution remains an important requirement not only for science, but the survival of the human race and improvement of man's quality of life. The effects of earthquakes, volcanic eruptions, and the cyclical ice ages entire species testify to this need very clearly.

Table B-9

THEME 06: USE OF ENVIRONMENT OF SPACE FOR
SCIENTIFIC AND COMMERCIAL PURPOSES

Objective	Basic Purpose
061 - Basic Physics and Chemistry	Perform basic and applied physical science laboratory-type experiments which require the space environment; primarily weightlessness
062 - Material Science	Advance of material science through research in a weightless environment
063 - Commercial Inorganic Processing	Determine the potential of commercial inorganic processing in a weightless environment
064 - Production/Isolation of Biologicals	Produce or isolate biological materials by processes which require weightlessness
064A - Commercial Processing of Biologicals	Determine the potential of commercial processing of biologicals in space
065 - Effects of Gravity on Terrestrial Life	Determine the effects of gravity on the evolution and forms of terrestrial life
066 - Man Living and Working in Space	Determine if man can live in full health and work efficiently for years in space

Table B-10

THEME 07: IMPROVE THE QUALITY AND AVAILABILITY OF HEALTH CARE

Objective	Basic Purpose
071 - Physiology and Disease Processes	Utilize weightlessness as a research tool to gain better understanding of physiology and disease in man
072 - Disease Carrying Insects	Utilize remote sensing for the identification and control of disease-carrying insects

Theme 08 defines issues relevant to understanding the dynamic processes of the earth which have been responsible for the occurrence of catastrophic events over millions of years and their potential recurrence in the future. Table B-11 lists the objectives to support this goal and the related one of understanding fundamental atmospheric phenomena.

Many of the automated spacecraft and associated operational systems to be used in accomplishing the objectives of Themes 01, 02, 03, 05, and 06 can also be used to support Theme 08. However, additional operational systems will also be required. These include:

- (1) Satellites to survey and measure magnetic field changes
- (2) Geodetic satellites
- (3) Satellites to monitor sea- and land-based sensors.

Table B-11

THEME 08: EARTH SCIENCE

Objective	Basic Purpose
081 - Earth's Magnetic Field	Determine the causes of the earth's magnetic field, and what the geomagnetic field can tell us of the earth's interior; monitor the earth's field
082 - Crustal Dynamics	Determine the nature and cause of crustal dynamics
083 - Ocean Interior and Dynamics	Develop an understanding of the ocean interior and dynamics
084 - Dynamics and Energetics of Lower Atmosphere	Develop an understanding of the dynamics and energies of the lower atmosphere
085 - Structure, Chemistry, Dynamics of Stratosphere/Mesosphere	Describe the structure, chemistry and dynamics of the stratosphere and mesosphere
086 - Ionosphere-Magnetosphere Coupling	Determine how the ionosphere is coupled with the magnetosphere

APPENDIX C

CANDIDATE IUS EXPERIMENTS AND INSTRUMENTS

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Appendix C
CANDIDATE IUS EXPERIMENTS AND INSTRUMENTS

1. INTRODUCTION

The Hearth Committee has identified a set of themes and objectives that should be supported by the application of NASA's capabilities. They defined a set of systems to support these objective areas and identified the major R&D activities required to implement these systems. The material generated by this committee is summarized in Appendix B.

In a separate activity, GE and Fairchild have been under contract to NASA's GSFC to identify candidate experiments/instruments for inclusion in IUS payloads and to group these experiments into a set of IUS payloads. To assure consistency of their study results with NASA programs structured to provide maximum support to the Hearth Objectives, SRI was selected to perform a study, one purpose of which was to determine the relevance to the Hearth Objectives of the experiments suggested by GE and Fairchild.^{C-1*} Table 1 in Section II of this report (reproduced as Table C-1 in this appendix) displays the potential relevance of the experiments listed by Fairchild** to the Hearth Objectives, as determined by SRI.

Each of the 33 experiments/instruments listed by Fairchild is identified below. A brief description of its uses is also given.

Following the listing of the experiments/instruments proposed by Fairchild, SRI presents a discussion to show how the relevance ratings shown in Table C-1 were obtained.

* Superscript numbers denote references listed at the end of this Appendix.

** The small size of the SRI effort precluded formal consideration of the experiments/instruments suggested by GE.

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Table C-1

IUS EXPERIMENTS/INSTRUMENTS CATEGORIZED BY OBJECTIVE

NO.	FAIRCHILD EXPERIMENTS/INSTRUMENTS	GLOBAL CROP PRODUCTION WATER AVAILABILITY LAND USE AND ENVIRONMENTAL ASSESSMENT LIVING MARINE RESOURCE ASSESSMENT TIMBER INVENTORY RANGELAND ASSESSMENT						LARGE SCALE WEATHER WEATHER MODIFICATION CLIMATE STRATOSPHERIC CHANGES AND EFFECTS WATER QUALITY GLOBAL MARINE WEATHER					
1	ORBITING STANDARDS PLATFORM												
2	MILLIMETER WAVE BROADBAND EXP.												
3	MILLIMETER WAVE SATELLITE-TO-SATELLITE EXP.											1	
4	HYDROMETER ATTENUATION DEPOLARIZATION EXP.	1	1					1					
5	RFI INVESTIGATION										2		
6	FIXED AND MOBILE SATELLITE COMMUNICATION		2								2	2	
7	ORBITAL ANTENNA RANGE												
8	RELAY STATION FOR DEEP SPACE PROBES												
9	ATMOSPHERIC X-RAY EMISSION DETECTOR	1	1				1	2	1	2	2		1
10	STEREO SEVERE STORM SENSING	2	2				1	3	3	2	1	1	3
11	MICROWAVE VERTICAL ATMOSPHERIC SOUNDER	2	1	2	2	2	3	3	3	3	1	1	3
12	MICROWAVE MEASUREMENT OF TEMPERATURE AND WATER VAPOR PROFILES	1	2	1	1	1	2	3	1	3	2	1	3
13	GEOSYNCHRONOUS CLOUD PHYSICS RADIOMETER	3	2		1		1	3	3	3	2	2	3
14	RADAR MEASUREMENT OF PRECIPITATION RATES OVER THE OCEAN		1		1			3	3	3	2	1	3
15	RADIO INTERFEROMETRY POSITION LOCATER												
16	CO ₂ LASER SYNCHRONOUS SATELLITE DATA RELAY RECEIVER EXP.							1			1	1	
17	GEOSYNCHRONOUS LASER REFLECTOR												
18	PRECISION ATTITUDE DETERMINATION SYSTEM (PADS)												
19	PRECISE & ACCURATE TIME AND TIME INTERVAL EXP. (PATTI)												
20	FUEL CELL												
21	ECLECTIC SATELLITE PYROHELIO METER												
22	HIGH VOLTAGE SOLAR ARRAY SPACE PLASMA DRAINAGE EXP.												
23	MERCURY ION ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
24	LIQUID METAL SLIP RINGS								2				
25	CESIUM ION ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
26	TEFLON ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
27	COLLOID ION ENGINE	2	2	2	2	2	2	2	2	2	2	2	2
28	DATA COLLECTION SYSTEM	1	1		1	1	1	2	2	2	2	2	2
29	MILLIMETER WAVE COMMUNICATION EXP.							1			1	1	1
30	ELECTROMAGNETIC ENVIRONMENT EXP.									2			
31	MULTIBEAM EXP		2								2	2	
32	INTEGRATED COMMUNICATION EXP.	1	2	1	1	1	2	3	2	3	2	2	3
33	1.5-M TELESCOPE RADIOMETER	3	3	3	2	2	3	3	3	2	1	3	2

KEY: 3 = STRONG RELEVANCE
2 = MODERATE RELEVANCE
1 = PARTIAL RELEVANCE

BLANK = WEAK, NONE, OR UNKNOWN RELEVANCE

 = STRONG TO MODERATE RELEVANCE
CITED FOR HEARTH SYSTEMS


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Table C-1 (Continued)

No.	LOCAL WEATHER AND SEVERE STORM	TROPOSPHERIC POLLUTANTS	HAZARD WARNINGS	COMMUNICATIONS/NAVIGATION	SOLAR POWER	POWER RELAY	HAZARDOUS WASTE DISPOSAL	WORLD GEOLOGICAL ATLAS	DOMESTIC COMMUNICATIONS	INTERCONTINENTAL COMMUNICATIONS	BASIC PHYSICS AND CHEMISTRY	MATERIAL SCIENCE	COMMERCIAL INORGANIC PROCESSING	PRODUCTION, ISOLATION OF BIOLOGICALS	COMMERCIAL PROCESSING OF BIOLOGICALS	EFFECTS OF GRAVITY ON TERRESTRIAL LIFE	MAN LIVING AND WORKING IN SPACE	PHYSIOLOGY AND DISEASE PROCESSES	DISEASE CARRYING INSECTS	EARTH'S MAGNETIC FIELD	CRUSTAL DYNAMICS	OCEAN INTERIOR AND DYNAMICS	DYNAMICS AND ENERGETICS OF THE LOWER ATMOSPHERE	STRUCTURE, CHEMISTRY, DYNAMICS OF STRATOSPHERE/MESOSPHERE	IONOSPHERE - MAGNETOSPHERE COUPLING
1	1		1	3	1?	1?			3	3													1	1	
2	2		2	3	1?				3	3													2	2	
3	1		1	2					3	3									1						
4	1		1	2					2	2	1'												1	1	
5	2			3					3	3													2	2	
6	2	2		3					3	3															
7	1		1	3	1?	1?			3	3	1												1	1	
8																									
9	1			2	1	1			1	1										2			3		3
10	3		2	2	1	1			2	2															
11	3		1	1	1	1			1	1													1	1	2
12	3	1																					2	3	2
13	3	3	3	1	1																		2	3	3
14	2		1																				2	2	
15			1	3	1	1			1	1			2	2			2								
16	1		1	3					3	3													1	1	
17				3		1			3	3															
18				3	3	3																			
19				3					1	1	2														
20	2		2	2	2	2			2	2			2	2			2								
21			1	2					2	2													2	2	2
22				2					2	2			2	2			2								
23	2	2	2	2		2		2	2	2								2	2			2	2	2	
24				2					2	2			2	2			2								
25	2	2	2	2		2		2	2	2								2	2			2	2	2	
26	2	2	2	2		2		2	2	2								2	2			2	2	2	
27	2	2	2	2		2		2	2	2								2	2			2	2	2	
28	3	2	3	3					3	3									2						
29	2	2	3	3					3	3													2	2	
30	2			3					3	3													2	2	
31	2	2		3					3	3															
32	3	2	3	3					3	3									2			2	3	2	
33	3	1						3	1	1									3			2	2		

KEY: 3 = STRONG RELEVANCE
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2. CHARACTERISTICS

The first 27 instruments listed in Table C-1 were identified in Reference C-1 and fall into six general discipline classes:

- (1) Classical Communications
- (2) Laser Technology
- (3) Meteorology
- (4) Navigation
- (5) Altitude Control
- (6) Supporting Technology

The instruments in each of these classes are listed below along with a summary of their intended uses.

Classical Communications

- | | |
|---|--|
| • Orbiting Standards Platform | Provide standard beacons and receivers for antenna calibration and static measurement of long-term statistics for signal propagation |
| • Millimeter Wave Broadband Experiment | Test broad bandwidth communication links from 40 to 800 GHz |
| • Millimeter Wave Satellite-to-Satellite Experiment | Evaluate high data rate communication links between Spacelab and synchronous satellites |
| • Hydrometer Attenuation/Depolarization Experiment | Obtain temporal and spatial attenuation and depolarization statistics from super high frequency to optical frequencies |
| • Radio Frequency Interference Investigation | Determine power levels of background RF emissions in selected frequency bands from L-band to millimeter wavelengths |
| • Fixed and Mobile Satellite Communications | Demonstrate band sharing between fixed and mobile services at C-band, X-band, and millimeter wavelengths |
| • Orbital Antenna Range | Measure ground-based and spaceborne antenna characteristics (50 MHz to 50 GHz) |
| • Relay Station for Deep Space Probes | Increase the performance reliability and channel capacity of deep space probes |

Laser Technology

- CO₂ Laser Synchronous Satellite Data Relay Receiver Experiment
Demonstrate feasibility of laser links between low-altitude and synchronous satellites
- Geostationary Laser Reflector
Provide long baseline measurements and in-orbit calibration

Meteorology

- Atmospheric X-ray Emission Detector
Identify mechanisms that trigger weather modifications during solar events
- Stereographic Severe Storm Sensing
Provide real-time detection of towering cloud buildup for tornado and severe storm forecasting
- Microwave Vertical Atmospheric Sounder
Demonstrate microwave atmospheric sounding technology
- Microwave Measurement of Temperature and Water Vapor Profiles
Improve detection and prediction of storm conditions
- Geosynchronous Cloud Physics Radiometer
Improve ability to monitor clouds using a six-channel radiometer with a 1-meter telescope
- Radar Measurement of Precipitation Rates over Ocean
Measure rainfall rates by a coherent radar using a synthetic aperture

Navigation

- Radio Interferometry Position Location
Accurately locate position of very low-power radio beacons by synchronous satellite
- Precise and Accurate Time and Time Interval (PATTI) Experiment
Define the requirements for PATTI for Spacelab missions

Attitude Control

- Precision Attitude Determination System (PADS)
Provide 0.001-degree attitude determination using three-axis, rate gyroscope and star tracker

Supporting Technology

- Fuel Cell
Provide 400-watt power source for eclipse

- Eclectic Satellite Pyroheliometer Measure solar constant of radiation and certain spectral components
- High Voltage Solar Array Space Plasma Drainage Experiment Support high voltage solar array technology for high-power broadcast satellites
- Mercury Ion Engine Support development of advanced north-south station-keeping technology
- Liquid Metal Slip Rings Support development of advanced sun oriented solar array technology
- Cesium Ion Engine Support development of advanced north-south station-keeping technology
- Teflon Engine Support development of advanced north-south station-keeping technology
- Colloid Ion Engine Support development of advanced north-south station-keeping technology

The last six experiments suggested by Fairchild are not included in their list in Reference C-1 but do appear in their list of instruments making up candidate IUS payloads. The first five are communication experiments; the last one is a 1.5 meter telescope radiometer that is needed to provide an advanced earth observation capability.

- Data Collection System Develop network to receive, process, and distribute observations and warnings in real time
- Millimeter Wave Communication Experiment Investigate propagation characteristics in 40-GHz and 90-GHz regions
- EM Environment Experiment (Seems to be same as RFI Investigation experiment, No. 5 in Table C-1. Available data insufficient to determine this.)
- Multibeam Experiment Provide L-band maritime telecommunications system
- Integrated Communication Experiment Is a cost-effective combination of experiments No. 1,12,28,29, and 30 (see Table C-1).
- 1.5-Meter Telescope Radiometer Develop advanced earth observation capability.

3. RELEVANCE RATINGS

SRI has evaluated the contribution that each of the 33 experiments/instruments selected by Fairchild can make to each of the 37 Hearth Objectives. A four-level rating scheme was used: 3, 2, 1, and 0 (or blank). The key to these ratings is as follows:

- (1) A rating of 3 was assigned to an experiment for its relevance to a given Hearth Objective if that experiment were judged critical to the operation or development of an operational system fielded to support the given Hearth Objective. For example, the 1.5 meter telescope radiometer experiment/instrument was given a rating of 3 for Hearth Objective 011, Global Crop Production, because an operational instrument with the resolution and multispectral capabilities of this candidate IUS instrument are required to realize the benefits possible in this application (objective) area.
- (2) A rating of 2 was assigned to an experiment for a given objective if it was felt that, although an operational system could be developed for this objective without flying the experiment in question, the performance level of the operational system would be markedly enhanced if the experiment were flown. For example, current station-keeping capabilities are probably sufficient to support operational systems capable of contributing to almost all of the Hearth Objectives. However, the development of ion engines to provide vastly improved station-keeping capabilities would markedly enhance the performance, for example, of advanced satellite communications systems by:
 - (a) increasing the number of satellites that could be assigned a given frequency band (because they could be stationed at smaller nominal separation distances and still provide resolvable transmission points and
 - (b) decreasing the costs of the ground-based antennas (because of a relaxation in the receiver/transmitter beam steering requirements).
- (3) A rating of 1 was assigned to an instrument for its relevance to a given objective if only a modest increase in the contribution to this objective could be identified from successful implementation of the experiment. For example, the condition of rangelands (Hearth Objective 016) is markedly dependent upon the amount of precipitation, some of which comes during severe storms; thus a system that provides severe storm information is of some utility in determining the quality of these lands. However, since the

primary method of using multispectral scan data is sufficient to achieve this Hearth Objective and since the condition of rangelands is more affected by long-term weather and grazing history than by isolated severe storms, only a modest contribution to this objective accrues from the Stereo Severe Storm Sensor in the list of candidate IUS experiments.

- (4) A zero (or blank) rating was given in those cases where the relevance of an experiment to a given objective was either weak, nonexistent, or unknown; for example, no measurable degree of relevance could be assigned the Orbital Antenna Range in supporting Hearth Objective 015, Timber Inventory.

Experiment/Instrument No. 10, Stereo Severe Storm Sensing, is used here to illustrate the process that SRI used in assigning the relevance.

The relevance number 2 appears twice for the first two Hearth Objectives (Global Crop Production and Water Availability). This means, that Stereographic Sensing has been judged to have "moderate relevance" to the "global crop production" and "water availability" objectives because knowledge of severe storms implies some knowledge of the associated rain level, which in turn can be used to aid in predicting crop growth and water availability in the area where these storms occur. On the other hand, it does not appear that severe storm sensing would have much impact on the next three Hearth objectives, land use and environmental assessment, living marine resource assessment, and timber inventory. The next Hearth Objective, Rangeland Assessment was assigned a relevance rating of 1, as justified above.

A severe storm sensing system is essentially a weather satellite. Since several local storms play an interactive role with other weather elements and thus with overall large scale weather, it was decided that the Stereo Severe Storm Sensing experiment was strongly relevant to the Hearth Objective 021, Large Scale Weather.

The real purpose of this experiment/instrument, however, is to detect and review in real time the rapid buildup of towering clouds associated with tornados or other severe storms embedded in active squall lines so that proper warning of these storms may be given to the public.

Thus, the strong relevance rating of 3 has been indicated for the Hearth Objective Local Weather and Severe Storms.

Further moderate relevance ratings of 2 were assigned to the objectives of Hazard Warning, Communication/Navigations, Domestic Communication, and Intercontinental Communication because, although appreciable benefits could accrue to these areas without the capability provided by a severe storm sensing system, the benefits achievable would be markedly enhanced by the availability of information from such a system.

Partial relevance ratings of 1 were deemed appropriate for the Objectives of Solar Power and Power Relay because the ability to detect severe storms and disseminate this information in real time is relevant to these two objectives only if the measure of severe storms would require microwave transmission. The benefits attributable to a severe storm sensing system in providing such information was judged to be small relative to the total benefits realizable from systems designed to satisfy these two objectives.

REFERENCE

- C-1. "Shuttle/IUS Payload Definition Presentation to GSFC," Fairchild Space and Electronics Co., (March 20, 1975)

APPENDIX D
FUNDING ALTERNATIVES

Appendix D
FUNDING ALTERNATIVES

1. INTRODUCTION

The concept that users should reimburse Government Agencies for beneficial services is not new. The User Charge Statute of 1951 provides such services should be "self-sustaining to the full extent possible."^{D-1*} Agencies were authorized to establish fair and equitable fees based on: (1) the direct and indirect cost to the government, (2) the value to the recipient, (3) public policy and interest, and (4) other pertinent facts. In 1965, President Johnson established a government policy of user charges for such services stating as a guiding principle: "The government does not charge to make a profit, but we should make a recovery of our costs in the cases of special services."^{D-2} By the 1970's, user charges were not uncommon not only for "funding" services provided by one agency for another but also for services provided for non-government organizations, foreign or domestic.

NASA has had a policy of charging for launch vehicle services for many years. Before January 1973, launch services for non-government entities were priced under flexible rules which allowed NASA to determine an appropriate price after considering the objectives of the missions and the benefits which might accrue to NASA and to the United States. A new policy was adopted in January 1973^{D-3} which applies uniformly to all non-U.S. government organizations whereby all such users will pay "full cost", that is, direct cost of the launch plus a share of indirect launch associated costs. Although this policy appears to be consistent with the recommended "pro rata recoupment" reportedly contained in regulations being drafted by the General Services Administration, it is not clear that it represents either sound economics or the best policy for NASA. The purpose of this

* Superscript numbers denote references listed at the end of this Appendix.

appendix is, therefore, to discuss alternative user charge systems with particular emphasis on their utility as methods to enhance non-NASA participation in early Shuttle/IUS R&D flights.

This study assumes that NASA goals and objectives are well-defined by the Hearth Committee report and, further, that if these objectives can be justified on a cost benefit basis, the Shuttle/IUS experiments directly applicable to Hearth Objectives are also justified. Even if this is so, however, the broad scope and advanced technology of the Hearth Objectives make it clear that NASA would be hard pressed to fund the required development programs without the participation of potential users and beneficiaries.

NASA has already funded a research project to examine user charge options. Since the study completed by RAND^{D-4} in January 1975 contains much greater depth of analysis than was possible under the time and budget constraints of this research, no attempt has been made to reestablish the theoretical bases for user charges. Instead, SRI has used the RAND findings as well as other literature sources to identify recoupment policies which could be helpful in encouraging outside participation in early Shuttle/IUS programs.

2. SUMMARY OF THE RAND FINDINGS

RAND examined the theoretical bases for establishing user charges by comparing six alternative pricing strategies against two major value criteria. The strategies included:

- (1) Marginal* pricing
- (2) Average pricing or full-cost recovery

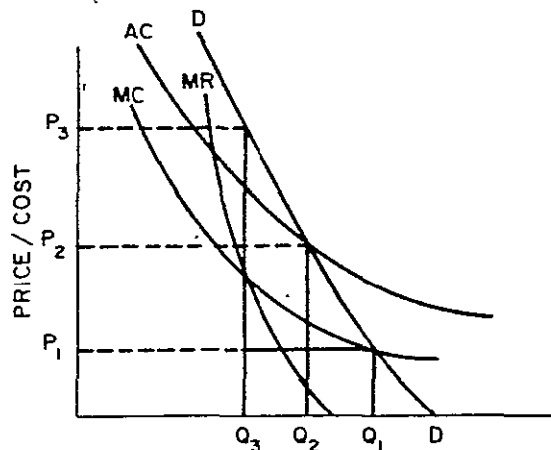
* The word "marginal" in this section is used in the sense of "next." For example, the "marginal flight" is the next flight being planned to accommodate potential sponsors, when there are other flights already firmly scheduled in this case, by NASA and the DoD; marginal pricing and marginal costs refer to pricing and costs associated with a marginal flight or launch.

- (3) Monopoly pricing which sets the price at the point where marginal cost equals marginal revenue and which will maximize returns to NASA
- (4) Entry-fee pricing which establishes a set fee for the first units for each customer
- (5) Two-part pricing, a variant of entry-fee pricing, which spreads the entry fee over the first q units where q is arbitrary but less than the total number of units the user is expected to buy, and
- (6) Price discrimination or more properly discriminant pricing where it is possible to sell each user a unit of a product or service at its marginal cost.

There are, of course, other pricing strategies available, some of which are discussed later in this paper.

RAND defined two principal criteria for evaluating alternative strategies: (1) efficiency and (2) equity. Efficiency criteria are used to evaluate alternatives from the standpoint of resource productivity and contribution to the gross national product. An alternative which resulted in resource costs exceeding the value of goods and services generated would be considered inefficient; whereas, an alternative which resulted in resource costs less than the value of goods and services generated would be efficient. Equity (distribution) criteria are used to evaluate alternatives from the standpoint of groups or sectors that would benefit and those that would pay. In essence, if a beneficiary pays less than his appropriate costs, then he is being subsidized by the group that does pay these costs. RAND points out that the distinction between these criteria is important since alternative strategies which contribute to the most efficient allocation of resources may not be the alternatives with preferred distributional characteristics. In addition it is also true that the goals of primary interest to NASA may, or may not, be the primary goals of other parts of government.

From the theoretical standpoint, marginal cost pricing and the several multipart pricing strategies (entry-fee, two-part, and discriminant pricing) are the most advantageous from an efficiency point of view (see 4, 5, and 6 above). RAND illustrated the superiority of marginal pricing with the following simple figure:



where DD is the demand curve; MR is the marginal revenue curve; AC is the average cost curve; and MC is the marginal cost curve. By equating the marginal cost curve and the marginal revenue curve, the formula for monopoly pricing ($Q_3 P_3$) can be obtained. Average cost pricing is represented by $Q_2 P_2$ while $Q_1 P_1$ is marginal cost pricing. Outputs Q_3 and Q_2 are inefficient and less than optimal since additional units of output will add more to national output than they will cost. Alternatives 4, 5, and 6 can be similarly efficient with properly selected entry fees (or variants therefrom). While strategies 2 and 3 are less than optimal, the penalty associated with them decreases as demand becomes less elastic. In fact, when demand is completely unresponsive to price, the line DD becomes vertical and output remains constant. In this case, the effect from moving from strategy 1, 2, or 3 is simply to raise prices and thereby redistribute real income from producers and consumers to the tax payers and government without any impact on the efficient utilization of resources.

After considerable analysis at a depth too great to reproduce here, RAND concluded that no single strategy is uniformly preferable in all or even most circumstances. A capsule summary of the analysis is as follows:

- (1) Most economists prefer pricing at long-run marginal cost. However, in many cases, there are enough public benefits from technology development to cover the R&D cost of the technology. If so, such R&D need not be included in the cost base.
- (2) Efficiency is not optimal for pricing above marginal cost. However, the associated penalties will be small

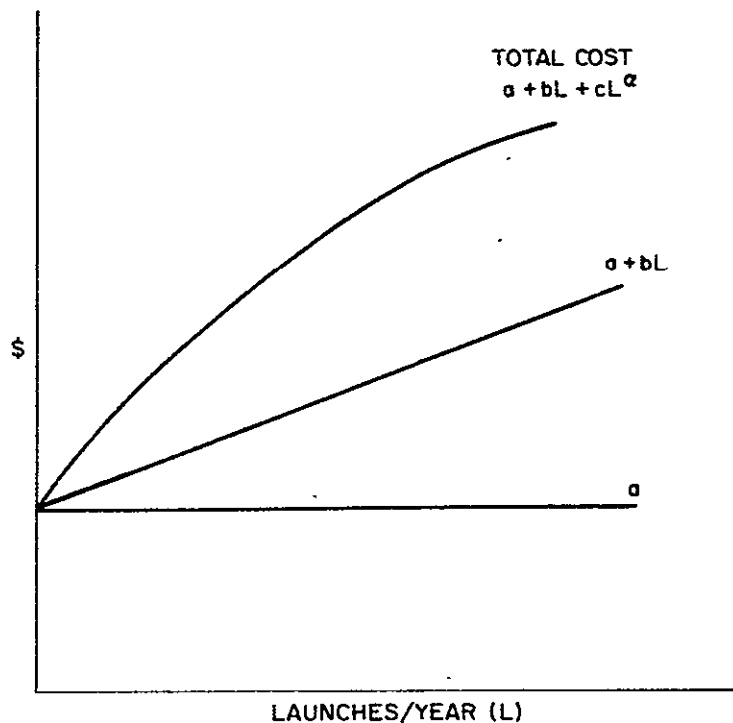
for many NASA-supplied services since demand for such services is relatively inelastic. A case-by-case analysis of price demand elasticity is required.

- (3) Departures from the equity (distribution) criteria incur penalties which must be determined by case-by-case analysis. In general, when the users and beneficiaries of a particular service are representative of the general population, distributional penalties will be small. Since the beneficiaries of improved telecommunications tend to be highly representative of the general population, equity penalties associated with alternative user charge strategies will be small. On the other hand, equity penalties associated with improved air transportation may be large since air travelers as a group are not generally representative of the general public.
- (4) In providing services for U.S. government users, short-run marginal cost pricing should be used since this is the resource cost to the government of providing the next (marginal) unit of service.
- (5) Although multipart pricing is perhaps unworkable because of computational and administrative difficulties, it should be seriously considered because of its efficiency and distributional advantages
- (6) The issues of efficiency and distributional equity are extremely complicated, do not lead to a single solution that is dominant in all cases, and need to be analyzed and judged on a case-by-case basis. NASA, therefore, has considerable latitude in selecting among user charge strategies.

Before turning from the RAND report to other considerations, it is important to note one observation concerning user charge strategies for launch operations.^{D-4*} RAND used the following simple diagram to describe average and marginal costs where a represents fixed costs, bL represents variable costs, and the function cL^α represents semi-fixed costs which vary less than proportionally with the number of launches (α less than 1). Total costs are given by the function

$$a + bL + cL^\alpha$$

* See pages 47-51.



Differentiating this expression gives the following equation for marginal cost

$$b + \alpha(cL^{\alpha}/L)$$

Thus, short-run marginal costs can be interpreted as direct costs (b) plus a share α (less than 1) of semi-fixed costs (cL^{α}). Thus, if a marginal cost pricing policy is used, NASA will not recover all of its costs. This condition will exist whenever the programs in question have decreasing unit average costs since marginal costs will always be less than average costs.

3. DISCUSSION OF PREVIOUS PRICING STUDIES

a. The RAND Study

This study was intended to be a theoretical examination of user charge strategies supplemented by case studies of particular NASA activities (launch service and aircraft noise abatement). Its output was intended for use by NASA management in evaluating agency-wide policy options. It

is not surprising, therefore, that RAND did not address many problems that are of particular importance to the more practical problem of applying user charge strategies to Shuttle/IUS flights.

The RAND report does discuss the differences between long and short run marginal costs and mentions the practical difficulties in measuring them. It is, in fact, difficult if possible at all to develop a function for the long-run marginal-cost curve associated with providing various services (such as those enumerated in the Hearsh Themes) from space. It is possible that reasonable approximations could be developed through an analysis of NASA expenditures since its inception. It is not clear, however, that the resulting functions would be worth the considerable effort required. Additionally, as the RAND report shows, penalties from pricing above marginal costs may be small if the demand for particular services is relatively inelastic. Since there may be easier ways to approximate either long- or short-run marginal costs than developing explicit functions, functional development does not seem to be required.

The major differences between long- and short-run marginal costs are the types of cost elements considered in each. For long-run costs, all cost elements are considered variable since in the long run there are no capacity constraints or other barriers. For short-run costs, money already spent is considered sunk since the decision to produce another unit of a service cannot influence what has already happened. Thus, long-run marginal costs would include consideration of all R&D, all facilities required to support the programs, and all similar costs that were incurred prior to the particular event of interest. In the short run, these types of costs are excluded in many cases since the short run reflects only those costs associated with orbiting a particular payload and maintaining it in operation for a specified period.

The RAND study examined only two applications on a case study basis. Neither of these (launch services or quiet engines) had any particular joint cost problems except perhaps for the fixed costs associated with launch operations. There were no joint costs in the economic sense because the cases studied involved a single user. In the Shuttle/IUS experiment

program, several users or customers may be involved in each flight. If a user charge strategy is to be useful, methods to assign costs to particular payloads will be required. Some costs will be readily identifiable by payload (e.g., hardware) while others (e.g., the launch and support costs) will be common to all payloads. While there is no economically sound way to allocate joint costs among users, several logical but arbitrary methods will be discussed below.

b. The Aviation Cost Allocation Study

The Airport and Airways Development Act of 1970 established a trust fund specifically designed to fund specified elements of the costs of the Federal airport and airways system. Congress intended that the users of the system should pay their share of its costs. In order to implement the provisions of the act, the Department of Transportation, after consultation with users, was directed to establish a system of user charges. As one step in this process, DOT sponsored a major study of the airport and airways system which included the development and evaluation of alternative methods for allocating costs among users as a basis for establishing user charges.^{D-5} Not surprisingly, study results were controversial since the various allocation methods (nine were tested) placed increased cost burdens on the several politically influential "users" of the system. Nevertheless, this was based on sound economics and analysis and its methods may be of use to NASA.

The airways allocation study,^{D-5} like the RAND work for NASA, developed methods for assigning costs to users and a set of criteria for evaluating the allocations. Unlike the RAND study, it had to treat many practical problems such as the measurement of marginal costs, the treatment of joint costs, and the ability to actually implement the various strategies. The study established the following criteria for evaluating alternatives:

- (1) Efficiency
- (2) Equity
- (3) Full recovery of costs, and
- (4) The users' ability to pay.

These were used to evaluate the following methods of assigning costs to users:

- (1) Units and measures of use
- (2) Benefits and value of service
- (3) Long-run marginal cost
- (4) Long-run incremental cost
- (5) Separable costs and remaining benefits

and others not necessarily pertinent to this discussion. Note that since the airport and airways system has, like launch services, decreasing unit average costs, allocations based on long-run marginal costs would not recover full costs as required by the Act. Because of this, a proportional long-run marginal cost allocation method was also developed.

DOT considered both the recovery of costs and ability of the user to pay as important measures of preference.* Both appear to be relevant to the Shuttle/IUS program. All of the allocation methods except (3) above result in user charges greater than marginal cost and are thus "inefficient" to some degree. In fact, since the methods do recover all costs in the cost base, the methods are, in effect, variants of average-cost allocation methods.

Both long-run marginal and long-run incremental cost methods were based on extensive statistical analysis. Least-square regression models were developed to explain the variation in costs of different system components in response to changes in the total use level and the mix of uses. Estimates of long-run cost behavior were based on a cross-section analysis of the system for a particular year (1971). The use of such a cross-section analysis is well documented in the literature. However, it does not appear that such analysis would be particularly fruitful in developing long-run costs for space system applications, because the statistical base is lacking.

Quite obviously, the DOT study methods are not directly applicable to the Shuttle/IUS problem, but they do contribute to the pool of user charge strategies available. The next section will outline a method of selecting

* The willingness of the users to pay was also considered to a limited extent.

among a reasonable set of alternatives which may encourage early participation in the Shuttle/IUS program by non-NASA sponsors.

4. SRI'S FUNDING STRATEGIES

a. General

Because of the increased government-wide emphasis on user charges and NASA's desire to increase participation in future payload development, methods for evaluating alternative user charge strategies are needed. This section presents a practical guide to the postulation and evaluation of such alternatives.

Perhaps the first goal of the methodology should be to retain for NASA a high degree of flexibility in establishing user charges. This will allow NASA to maximize benefits to the public, the government as a whole, and to NASA. Next, the methods should be analytically sound and defensible on economic as well as political grounds. This suggests that while the empirical derivation of margin cost functions is difficult, NASA should be aware of the efficiency penalties associated with alternative methods. Finally the methods should be adaptable to changing conditions as they may occur.

A process well calculated to achieve these goals consists of three steps:

- (1) Determine the cost elements in the pool of costs to be recovered (the cost base).
- (2) Postulate a set of recovery strategies
- (3) Evaluate the alternatives according to the following criteria: efficiency, equity, cost recovery, ability and willingness to pay, and administrative feasibility.

b. Cost Base Considerations

Through careful consideration, the pool of costs to be recovered can be constructed to yield proxies for marginal costs as well as measures of average cost. The first step is to assemble all the costs associated with the Shuttle/Tug program including the applicable costs at Headquarters and the centers. Next, "avoidable" costs should be determined. The term avoidable costs refers to those costs which would not be incurred if the

program (or next event) were cancelled. Finally the cost element structure should be examined to determine which elements (and to what degree) should be recovered. Theoretically, total costs divided by total flights yields average costs while avoidable cost divided by flights yields a proxy for marginal cost.

The selection of cost elements to be recovered is strongly influenced by long-run and short-run considerations. Since long-run costs assume "capacities" that are variable, all R&D and hardware procurement costs should be included. The short-run costs of a marginal Shuttle/IUS flight would certainly exclude the R&D cost since it is not avoidable.

However, Shuttle/Tug R&D Costs should probably not be included in the recoverable pool since the program has been approved by both OMB and Congress. This approval implies that both agree that the benefits of the program outweigh its costs. Most economists would agree that long-run marginal costs should be reduced by benefits accruing to the general public. Of course, major programs have been questioned even cancelled after initial approval in the past. Thus, if it seems likely that Congress may insist that the program "pay" for itself, then the user charge cost pool should include R&D costs. A clear solution of this problem is beyond the scope of this project.

It is less clear that Congressional approval of a program implies that investment costs in Shuttle/Tug hardware* should be excluded. However, because of the reusable nature of the vehicles, these costs will be small in relationship to total costs. Despite this, it seems likely that hardware costs should be included. If excluded, the order in which flights take place could have an influence on a particular user since new hardware or significantly higher refurbishment costs may be incurred for late program flights.

It should be clear from the definition, but it may be well to emphasize that avoidable costs can include both fixed and semi-fixed as well as

* Note that since the IUS is expendable, its procurement cost is included in marginal costs.

variable costs. Thus, it appears that an estimate of \$10 to 11 million for each flight for the Shuttle, reputed to be Direct Operating Cost, represents a cost below marginal cost and, therefore, is not a suitable basis for user charges. Certainly some indirect cost can be avoided if a marginal flight is omitted. Thus, charging only DOC for a Shuttle flight is in effect a subsidization of potential users by the taxpayers and seems to be neither good economics nor good politics.

c. Allocating Joint Costs

It is quite possible that a Shuttle flight will orbit a payload or provide services to a variety of users. If so, the treatment of joint costs becomes a much more important question than assumed in the RAND study. In addition, when examining the various IUS experiments it becomes clear that a single payload may have relevance to a number of Heath objectives and potential users. Therefore, the following methods of allocating costs to users emphasize the treatment of common costs.

Common costs can be allocated according to:

- (1) Units of Use - Allocations can be based on such measures as weight, power, or volume. Generally, the most restricted capacity should be used.
- (2) Benefits derived or value of service - Allocations can be made proportional to benefits received. The method cannot be used, of course, unless easily measurable and agreed-upon measures of benefits are available.
- (3) Separable costs - Allocations of common cost can be based on the total separable costs that can be identified with each user.

Other methods or variants of the above can be developed. In some cases, for example, it may be desirable to allocate common costs in a two-stage process. One method for achieving this is to examine each cost element to determine the user who is responsible for the cost. In a multi-purpose IUS experiment, for example, one application may require a sophisticated data collection system. If so, the cost of the system could be assigned to that application even if other applications make some (minimal) use of the device. The remaining common costs would then be allocated on some rational basis such as those above.

d. User Charge Strategies

The ideas discussed for determining the cost base can be combined with those for allocating joint costs to develop a series of alternative user charge strategies. These strategies can then be evaluated according to the following criteria: efficiency, equity, cost recovery, ability to pay, and administrative feasibility. The strategies are:

- (1) Long-run marginal costs - Given that the question of the public benefits from space can be answered, most economists would opt for this method of allocation since it leads to an efficient utilization of resources. The method would not, of course, recover all costs since it seems clear that Shuttle flights will have decreasing average costs. This could leave NASA with a sizable deficit. Pricing at the margin considers neither ability to pay nor equity and could be difficult to administer even if cost functions were available. The most difficult constraint for using long-run margins for user charges is the fact that a major research program would be required to develop the cost function. A statistical analysis of NASA launch and space vehicles could yield reasonable estimates of the cost functions involved.
- (2) Long-run costs - Long-run costs as a proxy for marginals could be developed through an analysis of the Shuttle/Tug and associated space vehicle programs. Allocation on this basis would be valuable, perhaps essential, if NASA believes that it must sustain the technological development of advanced space systems through user charges. The comments for long-run marginal costs and the evaluation criteria also apply here. More specifically, however, ability and willingness of potential users to pay will become a major concern.
- (3) Short-run marginal costs - This method is recommended for charging other U.S. government users since it reflects only those resources required to produce the next unit of service. Actually, the method for determining short-run incremental costs described in Appendix C of the RAND report^{D-4} can be applied to develop average yearly cost which will approximate the short-run marginals. Since this method is based on an analysis of projected costs for the year, NASA would recover all the costs deemed appropriate. Short-run marginal costs do not necessarily meet the efficiency

criteria since under- or over-utilization of facilities will cause deviations from true long-run marginal costs (which do meet these criteria). Short-run marginal pricing does not consider equity or ability to pay but is relatively easy to administer. Note that as a variant to a one-year basis for short-run marginal pricing, the cost pool could be extended to include the expected cost of the total program. This would tend to smooth out year-to-year fluctuations but errors in the required estimates could introduce problems.

- (4) Average Costs - User charges based on average costs would be inefficient since they would be greater than true marginals. Full costs would be recovered and administrative ease would be high. This method would not meet the equity or ability-to-pay criteria.
- (5) Two-part Pricing - Two-part pricing schemes are attractive for a number of reasons. As the RAND report points out, they are relatively efficient since marginal flights are priced at marginal costs. All costs can be recovered through proper structuring. While not responsive to equity or ability to pay considerations, it is possible that reasonable administrative procedures can be developed. A two-part pricing system, even though less precise than the ideal described by RAND, could serve as an attractive device to encourage early participation in the IUS program.
- (6) Value of Service - User charges based on benefits received would recover all costs, reflect the users' ability to pay, and has at least some equity implications. It would, however, be an administrative nightmare unless easily measurable and agreed-upon benefits could be determined. This does not seem to be the case, particularly in the early phases of the Shuttle program.

Many other allocation schemes can be postulated but it is interesting to note that even those discussed do not fare very well when compared against the pricing criteria established. This is shown in Table D-1. Other methods suggested in the literature seem no better. This analysis thus tends to confirm the RAND conclusion that no single method is preferred in all or even a majority of cases.

e. Relevance to IUS Program

This study defines a methodology for selecting IUS payloads designed to contribute to satisfying the needs of major agencies in accordance with

Table D-1
EVALUATION OF USER CHARGE STRATEGIES

Strategy	Criteria				
	Efficiency	Equity	Ability to Pay	Cost Recovery	Ease of Administration
Long-run Marginal	Yes	No	No	No	No
Long-run Costs	Partial	No	No	Yes	Partial
Short-Run Marginal	Partial	No	No	Yes	Yes
Average Costs	No	No	No	Yes	Yes
Two-Part	Partial	No	No	Yes	Partial
Value of Service	No	Partial	Yes	Yes	No

the goals specified by the Hearth Committee. The technology required for some Hearth Objectives will be expensive to develop and IUS experiments must be carefully controlled to meet budget constraints. Therefore, it is highly desirable to gain participation of non-NASA entities in the early IUS program. Hopefully, this participation will include funding for some of the IUS experiments which support the development of operational systems envisioned in the Hearth Report. In addition to establishing acceptable funding strategies for these essentially R&D activities of the IUS, NASA must also develop viable user charge strategies for the entire STS program since the success of this program depends, in part, on encouraging potential users outside of NASA and DoD to sponsor the marginal or next flight. Thus, NASA's user charge system has at least two objectives: to enhance early participation and to stimulate outside agencies to make use of the Shuttle.

SRI's review of Hearth objectives showed that there are at least two types of benefits: (1) hard benefits such as those that accrue from reduced long-distance communications, and (2) potential benefits such as those that would accrue if, and only if, users made use of better crop forecasts. Many of the Hearth objectives lead to substantial potential benefits. In most cases where potential benefits are involved, it is difficult to find users other than government agencies who would be willing to sponsor flights (singly or in combination) for operational systems, much less R&D. In some cases, substantial user charges could discourage the very utilization which would convert potential to realized benefits. There are, of course, other institutional constraints. Could crop forecasts, for example, be made available only to those who paid for them? Could those who paid get advance information? It seems doubtful since such forecasts have been public information and are widely used. (One flour producer, in assessing the impact of the recent Russian wheat purchases, has announced publically that the company will make no decision on a possible price increase "until we've seen the next crop forecast.")

Despite this, user charge strategies may stimulate both marginal use and early participation. Some two-part pricing strategy may have

advantages. If a potential user or beneficiary is willing to assume risks by early participation, he should thus be entitled to favorable cost treatment when the system is in operation. One method of achieving this would be to assume that the R&D investment constitutes an entry fee and that subsequent use would be priced at the margin. Those not participating in the R&D phase could be charged an entry fee with other services charged near the margin.

REFERENCES

- D-1. User Charge Statute, 31 United States Code (USC) (1964)
- D-2. Statement on User Charges by President Johnson at Cabinet Meeting (February 11, 1965)
- D-3. NASA Policy Directive (NPD) 8610.5 (January 1973)
- D-4. "Pricing and Recoupment Policies for Commercially Useful Technology Resulting from NASA Programs," R-1671 NASA, RAND Corp. (January 1975)
- D-5. "Allocation of Airport and Airways Systems Costs," Working Paper Number 10, Aviation Case Allocation Study, Department of Transportation (December 1972)