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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 05025

SUBJECT: Mission Effectiveness in Payload Planning - Case 234

DATE: May 7, 1969

FROM: F. G. Allen

ABSTRACT

A method is given for assessing the effectiveness of a manned space flight mission payload during the planning stage. Effectiveness is taken to be the performance of a given payload compared to the ultimate payload that could be flown on the given mission. The worth of the payload is found as a sum over all experiments assigned to the mission of four factors: 1) priority rating of the experiment discipline among agency goals, 2) priority rating of the experiment in its discipline, 3) rating of suitability to the particular mission, and 4) likelihood of success. General rules are given for assessing the total cost of the mission, as well as a set of performance indices. Comparison of worth, cost and performance indices for alternate payloads, together with an assessment of the resulting program of all missions should make possible a wise assignment of payloads.

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MEMORANDUM FOR FILE

Our purpose is to propose criteria and procedures for judging the effectiveness of manned space missions, with particular emphasis on the planning of payloads. While we address the effectiveness of individual missions, each mission must, of course, be viewed in the context of an entire program.

Frame of Reference

We are considering manned earth orbital mission payloads in the 1975-1985 time frame.

Mission will mean any given space station with its logistics flights and associated modules, or individual missions apart from space stations, and the experiment payloads assigned to each.

Mission Effectiveness will be taken to mean the performance of agency goals by a candidate mission payload as compared to the ultimate performance that can be conceived for that mission and spacecraft.

Assessment of mission effectiveness is viewed as a tool to judge competing missions in the planning stage.

Criteria

The two most important criteria for this effectiveness will be that

1. the worth of the payload should be maximized; and

2. the cost of performing the mission should be minimized.

By maximizing the worth and minimizing the cost, the "cost effectiveness" is automatically maximized.

The evaluation of worth and cost is, of course, extremely difficult in the real world. We shall first indicate the formal procedure one would use if all necessary formation and judgments were available. This is useful in structuring

the problem, and suggests simplified approaches. We later define a set of indices of effectiveness which, while not as generally useful as worth or cost, can be obtained more readily and serve as useful indicators for comparison.

The worth of a mission payload can be broken down as follows:

> Worth, (W_M) = A sum over all experiments, of Agency Priority among Disciplines, (P_A), times Priority of experiments within a Discipline, (P_D), times Likelihood of Success, (L_S), times Suitability to the Mission, (S_M).

Stated mathematically,

$$W_M = \sum_{i=1}^{N} P_{Ai} \cdot P_{Di} \cdot L_{Si} \cdot S_{Mi} \qquad (1)$$

where i pertains to the i th experiment on a payload of N experiments.

All terms on the right of (1) run from 0 to 100, the larger the number the better the rating.

Here

1) P_A is the priority of the discipline in fulfilling major agency objectives. For example, extension of manned mission duration during the AAP might rate P_A=100.

2) P_D is the priority of the experiment within its discipline. Thus, during the AAP an ATM experiment might rate a 100 among all astronomy objectives.

3) L_S is the likelihood of success, judged by a) reliability of investigating team, b) likelihood that hardware and systems will perform as planned, c) availability of fall-back results in degraded mode, and d) likelihood that decisive results will be obtained. (The latter takes account of the fact that some experiments are "gambles" for high stakes - i.e., even if all equipment works, no results may occur.)

4) S_M is the Suitability to the Mission, judged by the match between the experiment requirements and the mission's properties as to:

   a) orbital characteristics (earth coverage, resolution, radiation levels, sky visibility, etc.);

   b) availability of attitude or pointing control;

   c) duration;

   d) astronaut services available (number of crew hours, specialists, etc.);

   e) interference with other experiments.

The cost of the mission payload can be broken down into

1) experiment cost from definition through final data analysis;

2) cost of experiment integration into the spacecraft, including all special system and hardware requirements such as attitude control and telemetry;

3) weight, volume, and power requirements;

4) cost of separate module and all its systems, if required;

5) astronaut time required, from pre-flight training through post-flight briefings;

6) other disadvantageous factors, such as tying the schedule of launch to the readiness of all payload elements;

7) programmatic vulnerability in losing too much with one failure.

Effectiveness of Mission in Overall Program

Clearly, the effectiveness of not only individual missions, but of the overall program must be assessed. The results of this will in general provide guidance for choices among individual missions.

The general criteria the program as a whole must satisfy are

1) Balance and Completeness. No large gaps in attacking important agency or disciplinary goals.

2) Timeliness. First priority objectives fly first, and no missions go that will be out of date when flown.

3) Flexibility. Quick response to major discoveries or adaptation to program failures or changes.

4) Growth, with Big Goals. Major current objectives and a program leading to major capabilities in the future should be emphasized.

Procedure

I. To assess Mission Effectiveness, we must first have in hand or develop by analysis:

1) Broad agency objectives and priorities.*

2) Objectives and priorities in each discipline.*

3) One or more alternative missions to assess for a given time and orbit, with approximate configurations and logistics specified and a set of prioritized experiments assigned as a payload.

4) Likelihood of success of each experiment.

5) Suitability of each experiment to its assigned mission.

An appendix to this memorandum shows in tabular form:

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*Initial mission effectiveness can be estimated before all such priorities are assigned by arbitrarily assigning all objectives and disciplines equal priorities. Some suggested priority groupings are given in the appendix.

Figure 1 - Overall Assessment of Payload Worth

Figure 2 - Suggested Priority of Experiment Disciplines in Agency, P_A.

Figure 3 - Experiment Priority Within Discipline, P_D, for Various Disciplines

Figure 4 - Likelihood of Success of Each Experiment, L_S

Figure 5 - Mission Suitability of Each Experiment, S_M

In these figures, rough guidelines are given for assessing numerical priorities in all categories.

II. The procedure will then be

1) Perform the sums indicated in Equation (1) to obtain worth.

2) Estimate total costs of the mission:

   a) for the experiment payload;

   b) for the spacecraft, experiment modules, experiment integration and launch module cost;

   c) for the logistics cost;

   d) for the crew size and time required by experiments.

3) Calculate the following indices. These will be valuable in comparing missions, and can usually be obtained more readily than either the worth or cost:

   a) cost in dollars per pound of experiment flown;

   b) fraction of available payload capability (weight, volume and/or power) actually used;

   c) fraction of postulated crew time actually used;

   d) derive a mission-payload suitability factor from the experiment suitability factors, S_M, by summing up all experiment suitability factors times the weight in pounds of each experiment and dividing by the total weight of experiments.

4) A comparison of the worth values, with the cost values, aided by the indices in 3), should indicate a choice between alternate missions.

5) A master plot of all missions on a worth (vertical axis) versus cost (horizontal axis) will indicate general cost effectiveness.

III. To assess the entire program of missions, we must then add the objectives attacked by all individual missions, compare with the agency and disciplinary objectives and judge for completeness, timeliness, etc. Where gaps or duplications are found, individual missions must be replanned.

F. G. Allen

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Attachment
Appendix: Figures 1-5

APPENDIX

FIGURE 1 - OVERALL ASSESSMENT OF PAYLOAD WORTH

	Sciences Astronomy Physics Biology	Earth Applications Meteorology Geology Geodesy FAG Oceanography	Space Technology	Engineering/Operations Biomedicine
I. Priority of Discipline in Agency, P_A	DEPENDS	ON YEAR AND	PROGRAM RATIONALE	
		↓		
II. Priority of each Experimement within its Discipline, P_D	Normally Assigned by Space Science Steering Committees	Normally Assigned by SSSC or SA	Normally Assigned by Experiment Steering Committee of MSFEB, OMSF, MM and OART	
		↓		
III. Likelihood of Success, L_S	ESTIMATED BY DISCIPLINE OFFICE AND IN INTEGRATED PAYLOAD PLANNING			
		↓		
IV. Suitability to Mission, S_M	EVALUATED IN I. INTEGRATED PAYLOAD PLANNING			
$\sum$ All Experiments of $P_A \cdot P_D \cdot L_S \cdot S_M$ = MISSION WORTH		↓		

FIGURE 2 - SUGGESTED PRIORITY OF EXPERIMENT DISCIPLINES IN AGENCY, P_A, 1970-1980

	APOLLO 1969 - 1971	AAP 1972 - 1977	ADVANCED PROGRAMS 1978 →
HIGH (P_A = 90 to 100)	LUNAR {SCIENCE / EXPLORATION BIOMEDICINE BIOTECHNOLOGY	LUNAR {EXPLORATION / SCIENCE EARTH APPLICATIONS ASTRONOMY BIOMEDICINE BIOTECHNOLOGY	PLANETARY EXPLORATION ASTRONOMY EARTH APPLICATIONS MATERIALS PROCESSING LUNAR EXPLORATION BIOSCIENCE (EXOBIOLOGY)
MEDIUM (P_A = 80 to 90)	ASTRONOMY IN EARTH ORBIT EARTH APPLICATIONS ADVANCED TECHNOLOGY BIOSCIENCE	PLANETARY EXPLORATION SPACE PHYSICS BIOSCIENCE MATERIALS PROCESSING ADVANCED TECHNOLOGY	SPACE PHYSICS BIOTECHNOLOGY BIOMEDICINE
LOW (P_A = 70 to 80)	MATERIALS PROCESSING SPACE PHYSICS PLANETARY EXPLORATION		ADVANCED TECHNOLOGY

FIGURE 3 - EXPERIMENT PRIORITY WITHIN DISCIPLINE, P_D FOR VARIOUS DISCIPLINES

PRIORITY	Sciences Astronomy Physics Biology	Earth Applications Meteorology Earth Resources Geodesy Oceanography	Space Technology (Systems and Materials)	Engineering - Operations Biomedicine, Biotechnology
	Priority Classes Normally Assigned by Space Science Steering Committee	Priority Normally Assigned by SSSC and Applications Office	Priority Normally Decided by OART	Priority Normally Decided by OMSF and MM
HIGH (P_D = 80 to 100)	1. Results likely to be of fundamental importance in own discipline. 2. Decisive to establishment of major theory. 3. Likely to impact other sciences as well. 4. Discoveries likely. 5. May open new fields. 6. Urgent because of effects it may have on later experiments.	1. Test new systems capable of acquiring major un-met data needs. 2. Search for new techniques, and definition of data requirements. 3. New understanding of mechanisms (meteorology, oceanography) to permit better monitoring and control.	1. Results likely to affect technical strategy or emphasis of space program. 2. Results likely to open up major new space capabilities and techniques. 3. Results needed soon for major system design considerations.	1. Results essential for planning and scheduling future missions. 2. Results will decide mode of operation, use of man and space systems. 3. In-space check-out and test of critical systems. 4. Establishes prime requirements for support of man on long missions.
MEDIUM (P_D = 40 to 80)	1. Moderate to high significance in its field. 2. Addresses important questions in its field. 3. Likely to settle among alternative theories or extend present models. 4. Increases accuracy of important data.	1. Provides early, versatile operation, calibration and test of sensor systems. 2. Provides early data for user trial. 3. Supports on-going projects in major way (such as GARP).	1. Results needed to decide between future design alternatives of minor systems and subsystems. 2. Space confirmation needed on major operational systems or subsystems. 3. Extension of data on space behavior of critical materials and systems.	1. Results will be useful in planning and scheduling future mission operations. 2. Adds useful biomedical and biotechnology data. 3. Chooses best of several possible alternative modes.
LOW (P_D = 0 to 40)	1. Routine extension of former knowledge. 2. Useful results if space available. 3. Not likely to have major impact in its own or other disciplines. 4. No great advantage over ground-based experiment.	1. Will provide confirmation of predicted system performance. 2. Takes advantage of flight opportunity when available. 3. Can be reasonably handled by ground or aircraft tests.	1. Provides useful parameters for improved future design. 2. Few important decisions rest on outcome. 3. Reasonable extrapolations can be made from ground or aircraft tests.	1. Useful information to be had if time and space available. 2. Not essential for critical decisions. 3. Results can be reasonably predicted from ground or aircraft tests.

FIGURE 4 - LIKELIHOOD OF SUCCESS OF EACH EXPERIMENT, L_S*

	1. Reliability of Investigating Team	2. Likelihood that Hardware and Systems will Perform as Planned	3. Fall-Back Results in Degraded Mode	4. Likelihood that Decisive Results will be Obtained
GOOD (L_S = 60 to 100)*	(15 to 25) 1. Prominent in their field 2. Successful experience with similar space experiments in past 3. Good institutional support 4. Have demonstrated realism in analyzing problems	(15 to 25) 1. Straight-forward experiment with simple, proven equipment 2. No great complexity in space systems or astronaut support 3. Deadlines for flight schedule should be easy to meet	(15 to 25) 1. Major goals can be achieved even if prime mode fails 2. Even if hoped-for effect not found, answers will be decisive	(15 to 25) 1. Results will surely provide clear-cut answer to major question 2. No anticipated confusion or ambiguity
FAIR (L_S = 40 to 60)	(10 to 15) 1. Recognized in their field 2. Successful experience on ground -- little space experience 3. Adequate institutional support 4. Realistic about problems	(10 to 15) 1. Moderate complexity 2. Some past experience with similar equipment 3. Schedule probably o.k.	(10 to 15) 1. Some goals can still be achieved if prime mode fails 2. Some useful results seem assured in any case	(10 to 15) 1. Reasonable chance of answers of major significance 2. Some ambiguity likely
POOR (L_S = 0 to 40)	(0 - 10) 1. New and unknown 2. No past experience 3. Little understanding of problems	(0 - 10) 1. Equipment and space system support highly complex; high reliability required for results 2. Advanced state of the art-little past experience 3. Flight schedule hard to meet	(0 - 10) 1. No fall back results if prime mode fails 2. No useful results if hoped for effect not found	(0 - 10) 1. Ambiguity very likely 2. Probability of finding desired results very low

* Find L_S for each experiment by adding scores from columns 1 through 4.

FIGURE 5 - MISSION SUITABILITY OF EACH EXPERIMENT, S_M

	1. Orbital Altitude and Inclination	2. Attitude and Pointing Control	3. Duration-Experiment Time	4. Use of Astronaut Services	5. Interaction with other Experiments
GOOD (S_M = 75 to 100)*	(15 to 20) 1. Optimum match for experiment's requirements as to a) Earth coverage b) Earth resolution c) Sky coverage 2. Special requirements as to magnetosphere, atmosphere, radiation belts, etc.	(15 to 20) 1. Spacecraft and pointing platforms well adapted to meet experiment requirements	(15 to 20) 1. Longest time desired easily met	(15 to 20) 1. Accessibility of trained astronaut crucial to success of experiment 2. Small astronaut services provide major improvement in experiment	(15 to 20) 1. Assists and complements others in essential way 2. Imposes no undesirable constraints on others
FAIR (S_M = 25 to 75)	(5 to 15) 1. Satisfies most of above requirements with some compromises	(5 to 15)	(5 to 15) 1. Long enough duration to achieve a significant part of goals	(5 to 15) 1. Experiment greatly improved or extended by presence of astronaut, but can fly without 2. Needs to be flown with astronauts present, but takes no time	(5 to 15) 1. Gives useful auxiliary data 2. Constraints and interference imposed still allow most other experiments to function properly
POOR (S_M = 0 to 25)	(0 - 5) 1. Severely compromises experiment objectives 2. Other missions available providing better match with requirements	(0 - 5)	(0 - 5)	(0 - 5) 1. Little need for any astronaut	(0 - 5) 1. No results useful to other experiments 2. Imposes severe constraints on other experiments 3. Produces objectionable interference--noise, vibration, or radioactivity, etc.

* Find S_M for each experiment by adding scores from columns 1 through 5.

BELLCOMM, INC.

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From: F. G. Allen

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