NASA-CR-66357 END

STUDY OF THE INFLUENCE OF SIZE OF A MANNED LIFTING BODY ENTRY VEHICLE ON RESEARCH POTENTIAL AND COST

FINAL REPORT

Part VI: Research Vehicle Size Selection and Program Definition

May 1967

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FOREWORD

This document is a part of the final report on a "Study of the Influence of Size of a Manned Lifting Body Entry Vehicle on Research Potential and Cost," conducted by the Martin Marietta Corporation, Baltimore Division, for the National Aeronautics and Space Administration, Langley Research Center, under Contract NAS 1-6209 dated April 1966. The final report is presented in eight parts:

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ABSTRACT (Total Study)

This study presents data—based upon a developed logic, task definitions, vehicle criteria, system analyses and design, and concepts of operation and implementation—with which the usefulness and cost of an entry flight research program can be evaluated.

The study defines 52 specific research tasks of value in developing operational lifting body systems, primarily for near-earth missions. Parametric design and performance data are evolved within a matrix of 5 vehicle sizes (with 1, 2, 4, 6 and 8 men) and 4 boosters (GLV, Titan III–2, Titan III–5 and Saturn IB) for all flight phases, from launch to landing. The design studies include vehicle arrangements, weight, aerodynamic heating and subsystem details. Systems integration analyses yield both design data, subsystem tradeoffs, and development and operations plans; and they lead, in turn, to cost effectiveness analyses which become the primary basis for vehicle and program selection.

A 25-foot long, 3-man vehicle weighing 12,342 pounds is selected for a research program of 9 manned (plus 2 unmanned) flights. This vehicle performs the maximum number of tasks and affords the highest research value per unit cost and the lowest cost per unit of payload in orbit; the estimated program cost is $1 billion. A detailed preliminary design of this vehicle is accomplished, including layout drawings and descriptions of each subsystem to identify available hardware as well as future options. Modifications for secondary research objectives—rendezvous and docking and supercircular entry—are considered.

The study also includes a brief examination of 2 smaller unmanned vehicles as alternate approaches to reduce cost.

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SUMMARY

This part presents the operations analysis done in support of NASA Contract NAS-1-6209 entitled "Study of the Influence of Size of a Manned Lifting Body Entry Vehicle on Research Potential and Project Cost."

The developed value and cost assessments combined with other pertinent considerations form the basis for selecting the entry vehicle size designated D/3, and a research plan of 11 flights. The designation D/3 stands for a particular entry vehicle, 25 feet (7.6 m) in length, with internal volume sufficient for a crew of six but equipped for three crewmen on the research flights.

The selected D/3 vehicle and 11-flight program provides capability to carry out 50 of the 52 candidate research tasks defined in this study. Research task loading on the series of 11 flights results in full utilization of crew capability and provides an average of 376 pounds (170 kg) of allocated experiment weight unused and available for possible weight growth or new experiments. Of all the candidate designs analyzed, the D/3 vehicle exhibits the highest research value per unit cost, the maximum number of tasks assigned, and the lowest cost per unit of payload weight in orbit.

Two special flight loading models, developed for this study, are used to evaluate the research potential of the candidate vehicle design and flight plan combinations. One model is completely automated by a linear programming technique with an auxiliary input generator.

Cost estimates of candidate vehicle and program combinations were computed using the Martin Marietta Space System Cost Model which relates data from similar historical systems to produce program cost estimates. Final selected D/3 vehicle costs for both a 7- and an 11-flight program were computed by the Martin Marietta Coincident Cost Model to provide a detailed program and subsystem breakout and fiscal funding requirements. The total costs of 7- and 11-flight programs were estimated at $853 million and $1003 million, respectively.

The D/3 vehicle is also evaluated qualitatively with respect to considerations of landing visibility, experiment packing density, supercircular entry capability, rendezvous and docking adaptability, and operational adaptability. The D/3 vehicle meets these criteria satisfactorily.

I. INTRODUCTION

This part of the final report on a "Study of the Influence of Size of a Manned Lifting Body Entry Vehicle on Research Potential and Cost" discusses the cost and effectiveness analyses performed. The objectives of these analyses were as follows:

(1) Enable assessment of the influence of vehicle size and crew size on capability for performing entry research.

(2) Provide the basis for selection of the optimum size vehicle and crew.

(3) Provide the basis for selection of the optimum flight plan.

(4) Provide realistic, detailed cost estimates for the recommended vehicle and research program.

The overall study approach was implemented in four basic phases encompassing a number of study tasks as shown in figure 1. These phases are:

Phase I--Problem Definition

Phase II--Flight Vehicle Selection

Phase III--Flight Vehicle Design

Phase IV--Program Selection

Phase I consisted of definition of (1) research tasks, (2) candidate flight vehicle configurations, and (3) candidate flight programs. These efforts are reported in Parts II, IV, and V, respectively.

In Phase II, a cost/effectiveness analyses coupled with selected "other considerations" was used to select the preferred entry vehicle and crew size. Effectiveness was measured in terms of the "value of research performed." This required the establishment of a numerical value for each research task and the identification of flight loading constraints. A heuristic flight loading model was then used to optimize the value of each vehicle/crew size-flight program size combination. A computerized flight loading model was used to check the results of the heuristic analysis. An existing cost model was modified to aid in the computation of the total program costs for each vehicle/program combination.

Phase III consisted of defining the selected entry vehicle design in detail. The results of this phase are reported in Part VII.

In Phase IV, Program Selection, a value sensitivity analysis was made, which required the use of the flight loading computer program. The computerized flight loading model was used to develop data required to justify the recommended flight plan. Phase IV also included the preparation of detailed cost estimates of the recommended research program for the selected vehicle.

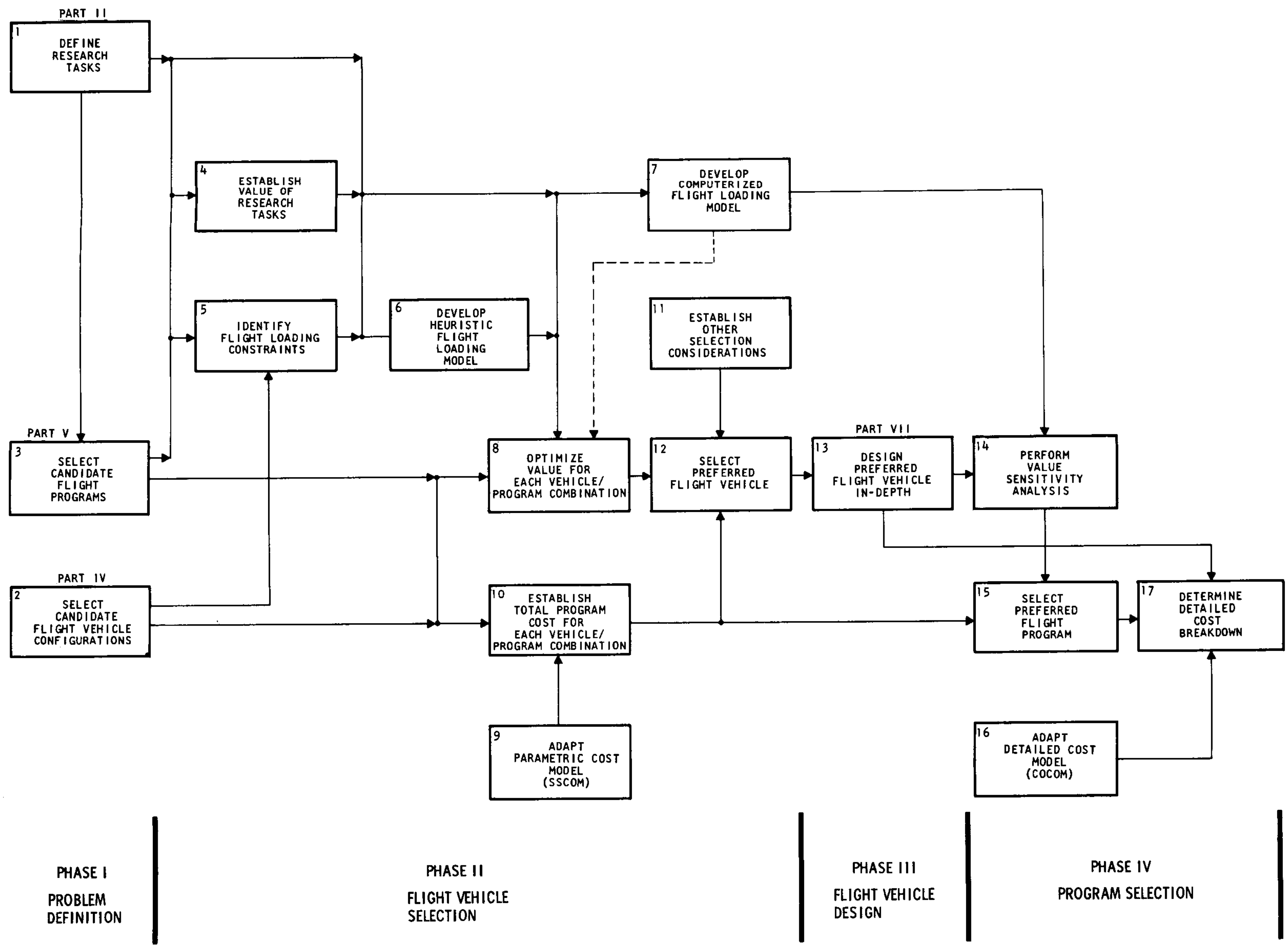

FIGURE 1. METHODOLOGY USED IN THE OVERALL ANALYSES

The methodology used in the vehicle selection process of Phase II consists of three principal steps: (1) establishment of inputs and constraints,(2) develement of analytical tools,and (3) analysis of candidate systems including display of results and final selection of vehicle/crew size. These steps are discussed in sections II, III, and IV of this part,respectively. Establishment of usable inputs required modification of the research value to account for probability of data acquisition and multiple assignment. Analytical tools developed for this study include both a heuristic and a computerized flight loading model, a special input generator program for the computerized model, and two cost analysis models especially chosen for costing of candidate and selected research programs. The heuristic model used the same inputs and constraints as those later applied to the computerized loading model, but loaded research tasks by manual "judgment" processes. Linear programming techniques were used for computerized loading.

Five different entry vehicles sized for full crew complements of 1, 2, 4, 6, and 8 in combination with various flight crew numbers were analyzed for several flight plans. Research values and costs of these candidate vehicles were then displayed and compared. The best vehicle/crew size was identified by the value/cost criteria and examined considering qualitative criteria and the final selection made. The selection process and results are found in section IV of this part.

Selection of the optimum research program using the selected vehicle was then made and costs determined. The selection process is treated in section V and the costing results shown in section VI of this part. A detailed description of development and operational plans is included in Part V.

II. INPUTS

The vehicle size selection and program definition tasks depend upon data generated in other phases of the study. Generally, these data require no adjustment or modification; e.g., the equipment weight and crew capability to support research tasks. In other cases, the data must be adjusted to suit the analytical techniques employed. It is the purpose of this section to provide a focal point for data developed in other parts of the study, and to discuss the refinements and assumptions that were made.

A. DEFINITION OF RESEARCH TASKS

Fifty-two research tasks (experiments) are identified in Part II. Each of these tasks is assigned an alpha-numeric designation; e.g., SM-1 identifies the first, although not necessarily highest valued, Structural-Mechanical research task. For purposes of the selection analyses, the identification of the research task and certain pertinent characteristics is required, while the particular nature of the research is not considered.

1. Intrinsic Value

Part II described the intrinsic value (i.e., research worth) that was developed using the psychophysical techniques of Pair Comparison and the Law of Comparative Judgment. The intrinsic values reported in Part II range from 1 to 237, and are a minor refinement upon initial values used in the selection analyses. The intrinsic values used in the selection analyses are reported in table 1.

The technique used to develop intrinsic research value, V_0, required arithmetic adjustment of the scale to result in positive worth for all tasks. This adjustment was made to equate the lowest valued task to unity. It is acknowledged that all tasks will yield positive results if completed but the geometric relationship of value between the most highly regarded and least highly regarded experiments is a matter of judgment. Because of the arbitrary nature of the arithmetic adjustment, it is necessary to determine the sensitivity of the results to various alternative adjustments.

Two alternative arithmetic adjustments were evaluated in comparison with the selected adjustment. The selected scale ranges from 1 to 245, and alternatives selected for evaluation are 1:10.4 and 1:3.4 which were produced by increasing the least regarded experiment value by 10 percent and 40 percent of the highest value, respectively. The potential research value of the D/3 vehicle in a five-flight program was determined with the flight loading model for each value scale.

The task loadings for each of the analyses are presented in table 2. Two significant conclusions are apparent: (1) Only four experiment assignments are changed with only two of these cases changing the information value of the experiment; (2) the research value of the total program is shifted less than 0.08 percent.

TABLE 1

RESEARCH TASK CHARACTERISTICS

Research task	Intrinsic value	Crew participation*	Equipment weight	
			lb	kg
SM-1	244.8	0	0	0
FM-8	223.2	0	20	9
FM-3	222.3	.4	0	0
FM-2	222.0	.5	0	0
FM-7	191.5	0	0	0
FM-4	154.1	0	0	0
GN-4	152.5	0	100	45
GN-5	150.3	.8	100	45
FM-13	146.8	0	0	0
GN-1	146.7	.3	0	0
EV-2	146.4	0	0	0
FC-1	145.2	.2	0	0
FM-5	144.9	0	0	0
SM-6	128.8	.1	50	23
SM-2	128.1	0	0	0
SM-8	124.1	0	0	0
FM-17	123.1	.3	0	0
GN-6	108.3	0	75	34
FM-14	102.1	0	0	0
GN-2	90.8	0	0	0
SM-17	86.4	0	0	0
SM-7	86.1	0	0	0
SM-5	85.2	0	10	5
SM-9	81.6	.3	135	62
SM-3	81.1	0	10	5
GN-3	79.6	0	50	23
FM-6	79.3	.4	250	113
FC-2	75.0	.1	0	0

*Fraction of one man's time required for task completion during critical flight period.

TABLE 1.--Concluded

RESEARCH TASK CHARACTERISTICS

Research task	Intrinsic value	Crew participation*	Equipment weight	
			lb	kg
FM-12	74.4	0	0	0
FC-3	71.0	.1	70	32
GN-7	65.6	0	50	23
SM-14	63.5	0	35	16
FC-4	63.5	.1	200	91
FM-15	63.1	0	15	7
PP-3	62.8	.4	150	68
HF-2	56.8	0	20	9
SM-10	55.9	0	0	0
SM-12	55.7	0	0	0
PP-2	55.0	.3	0	0
SM-13	44.7	0	0	0
PP-1	43.4	0	0	0
SM-11	40.0	0	0	0
SM-16	34.5	0	0	0
AV-2	33.2	.2	40	18
HF-1	31.9	.7	500	226
FM-16	27.4	0	40	18
SM-15	22.7	.8	80	36
FM-9	20.4	0	25	11
AV-1	14.7	0	0	0
FM-18	12.5	.5	200	91
SM-18	5.1	0	300	136
FM-19	1.0	0	0	0
Baseline tasks (must be assigned)	--	.7	--	--

*Fraction of one man's time required for task completion during critical flight period.

TABLE 2

SCALE SENSITIVITY ANALYSIS

Research task	Basic value scale loading 245:1					Adjusted value scale loading* 10.4:1 and 3.4:1				
	Flights					Differences				
	1	2	3	4	5	1	2	3	4	5
SM-1		•	•							
FM-8		•	•	•						
FM-2			•	•						
FM-7		•	•	•						
FM-13			•	•						
EV-2					•					
SM-6		•	•	•						
GN-1			•	•	•					
SM-2			•	•						
SM-8					•					
FM-14			•	•						
SM-7		•								
FM-12		•	•	•						
SM-5		•	•	•						
SM-17		•	•	•						
SM-3			•	•						
SM-9			•		•				•	X
FM-15		•	•	•						
PP-3			•	•						
GN-7				•	•					
SM-14		•	•							
HF-2			•	•						
SM-10			•		•				•	X
SM-12					•					X
SM-13		•	•	•	•					
PP-1	•	•								
SM-16			•	•						
AV-2		•								
SM-11			•						•	
FM-16			•	•						
SM-15					•					
AV-1		•	•	•						
Residual weight	1030	860	545	665	765	1030	860	545	530	900
Residual crew	-	-	.7	1.0	.9	-	-	.7	.7	1.2
Value	1227.231					1226.323				

*X indicates deletion; • indicates addition

It is concluded that the decisions made in this study are not sensitive to arithmetic adjustment of the value scale.

2. Resource Constraints

Each candidate research vehicle has certain capabilities such as weight and volume available for research equipment, crew time and electrical power available to operate this equipment, and instrumentation capacity to measure and record significant parameters from each research task. These five capabilities are designated vehicle resources and of course the number of research tasks that can be carried in any one vehicle could be constrained by the amount of these resources available. The way these resources were considered in this study is discussed below.

It became evident early in the study that a large portion of the research measurements called for common instruments. Summing the instrumentation for a given set of research tasks can be accomplished by a computer program. However, the large number of flight loadings used in the tradeoff analyses prohibited the use of this technique. As a result, it was decided to include the instrumentation and signal conditioning weight as part of the basic entry vehicle, and allow enough channels to handle the heaviest experiment loading. This baseline weight was derived from the most densely loaded flight of a series of 11 as derived from a preliminary manual analysis. The number of channels for this case totaled 2000.

The electrical requirements for powering research equipment determine the size of the battery for each flight. Battery size contributes to equipment weight, and this weight allowance for each task is combined with the primary equipment required for that task.

Vehicle volumetric constraints are related to the equipment weight by density characteristics. Thus, the weight resource for vehicle equipment was constrained by conservative research equipment densities.

Having adopted alternative techniques for the latter three qualities, the resource constraints utilized in assigning research tasks to entry vehicles are crew participation and equipment weight.

The equipment weight was estimated by listing the major components for each task, the weights installed, and the equivalent battery weight. The equipment description and equivalent weights are given in Part II. Weight data are summarized for all the research tasks in table 1.

The crew participation requirements for research tasks are reported in Part II. These constraints relate to 12 phases of the mission. The analytical techniques would become quite unwieldy if the crew requirements in all phases of flight are recognized as constraints. Fortunately, examination of the data indicates one phase during the entry period is consistently critical. The period from pullout (approximately 17.5 ksec in the mission) to 200 000 feet (approximately 60 km) was selected as presenting the most severe crew constraint. The recommended flight program is examined later to ensure this constraint was indeed adequate. The selected crew requirement data are summarized for for all research tasks in table 1.

3. Research Value

Value of a research task when loaded on a flight plan is determined by modifying the intrinsic value, as presented in table 1, by two modifiers: (1) informational value and (2) expectancy of obtaining informational value. The total value of an experiment, V_j, is expressed as a product of intrinsic value, informational value, and the probability of obtaining information value:

$$V_j = V_0 \sum \left[V_I\right] \times \left[P_I\right]$$

where

V_0 = intrinsic value

$\left[V_I\right]$ = informational value: ratio of information obtained to maximum information obtainable

$\left[P_I\right]$ = probability of achieving V_I.

Informational value, V_I, was established by a technical judgment technique which has some of the characteristics of information theory. Six categories of informational value were selected to aid computation since the exact expression for V_I involves mathematical expression of variables beyond the scope of this study. The top category of V_I is set at unity and is obtained when loading a research task on the set of entry conditions estimated to yield maximum possible information. These maxima are expressed in the research task descriptions in Part II. The bottom category was assigned a value of 0.45, a compromise between 0.3 and 0.6--the range of values in which test planners appear to reject an experiment as not worth loading on a flight program. The middle four categories were estimated by allowing the gain in value from one category to the next higher equal to one-half the difference between unity and that first category value. This results in an approximate exponential set of values:

Category	1	2	3	4	5	6
V_I	0.45	0.70	0.85	0.94	0.99	1.0

Using the above value categories, the number of flights assigned was evenly distributed in each category. For example, a research task may give maximum value for six flights and a minimum value for one flight of a given entry condition, resulting in the following V_I scale:

Category	1	2	3	4	5	6
V_I	0.45	0.70	0.85	0.94	0.99	1.0
No. of flights	1	2	3	4	5	6

In the above example, one flight would allow 45 percent of the potential value, three flights would yield 85 percent, and five flights would yield 99 percent; above six flights, the gain in information is negligible. Informational value, V_I, has been derived for each of the 52 research tasks and 8 baseline tasks. These inputs are listed in table 3 for all probable sets of flight conditions.

The probability of achieving information value, P_I, expresses the probability of acquiring research information on any given set of flights and is expressed as

$$P_I = (P_s)^{n-r} (1-P_s)^r$$

where P_s is the probability of success for a task on one flight

n = number of flights in set

r = number of failures.

The term P_s is then the product of flight mission success (exclusive of the research task) and the probability of acquiring usable data from a research task on a single successful flight. The probability of success, P_s, was derived from the reliability goals established for a mission success of approximately 0.9 and data acquisition probabilities ranging from 0.9 to 0.99 depending on the experiment and entry environment. Values of P_s are listed in table 3.

The total experiment value, V_j, was then obtained by summing the $V_I P_I$ terms for all single, double, and triple (if significant) failure events and modifying V_0 by this sum. The following example is shown for a sequence of entry conditions A, B, C, and C in which P_s = 0.85 and V_I = 0.45 for one B condition flight and 1.0 for one B plus one C flight. The example task is loaded on the B and first C conditions. Conditions A and B are prerequisites to C and must be successful before C condition can be programmed.

Entry condition	A	B	C	C	$P_I = (P_s)^{n-r} (1 - P_s)^r$	V_I	$P_I V_I$
No failures	S	S	S	S	$(0.85)^4 = 0.522$	1.0	0.522
Single failures	S	S	F	S	$(0.85)^3 (0.15) = 0.092$	0.45	0.041
Single failures	S	S	S	F	$(0.85)^3 (0.15) = 0.092$	1.0	0.092
Double failure	S	S	F	F	$(0.85)^2 (0.15)^2 = 0.016$	0.45	0.007
							$\Sigma P_I V_I = 0.662$

$$V_j = 0.662\ V_{0j}$$

TABLE 3
FLIGHT LOADING VALUE

Research task	Informational value, V_I, for flight condition sets						Probability of success, P_s			
	1.0	0.99	0.94	0.85	0.70	0.45	A	B, C D, F I	G	H, J K, S
SM-1	BC*	--	--	--	C*	B	NA	0.85	NA	NA
FM-8	B+6(C,F)	B+5(C,F)	B+4(C,F)	B+3(C,F)	--	B+2(C,F)	NA	0.85	NA	NA
FM-3	C+9[A,B]	C+8[A,B]	C+7[A,B]	C+6[A,B]	C+4[A,B]	C+3[A,B]	NA	0.87	0.86	0.85
FM-2	6(C,D,F)	5(C,D,F)	4(C,D,F)	3(C,D,F)	--	2(C,D,F)	NA	0.87	NA	NA
FM-7	B+6(C,F)	B+5(C,F)	B+4(C,F)	B+3(C,F)	--	B+2(C,F)	NA	0.87	NA	NA
FM-4	4[A,B]	--	3[A,B]	--	--	2[A,B]	NA	0.85	0.84	0.84
GN-4	2(C,F)2G	--	1(C,F)2G	2(C,F)G	--	1(C,F)G	NA	0.89	0.89	NA
GN-5	2(C,D,F)2G	--	--	1(C,D,F)2G	2(C,D,F)G	1(C,D,F)G	NA	0.89	0.89	NA
FM-13	6(C,D,F)	5(C,D,F)	--	4(C,D,F)	3(C,D,F)	2(C,D,F)	NA	0.85	NA	NA
GN-1	2C4F4G*	2C3F3G*	2C2F2G*	2CF2G*	2CFG*	CFG*	NA	0.88	0.86	NA
EV-2	10R	8R	4R	3R	2R	1R	0.85	0.89	0.89	0.89
FC-1	C+7[A,B]*	C+6[A,B]*	C+5[A,B]*	--	C+4[A,B]*	C+3[A,B]*	NA	0.88	0.88	0.87
FM-5	3[A]	--	--	--	--	2[A]	NA	0.88	0.88	0.87
SM-6	B2C	--	B2F	BCF	--	BC	NA	0.85	NA	NA
SM-2	2C	2F	CF	--	C	F	NA	0.86	NA	NA
SM-8	10R	8R	4R	3R	2R	1R	0.85	0.88	0.88	0.88
FM-17	3(C,F)2I	3(C,F)I	2(C,F)2I	2(C,F)I	C2I	1(C,F)I	NA	0.85	NA	NA
GN-6	4[A,B,S]	--	--	3[A,B,S]	--	2[A,B,S]	NA	0.89	0.89	0.89
FM-14	6(C,D,F)	5(C,D,F)	--	4(C,D,F)	3(C,D,F)	2(C,D,F)	NA	0.86	NA	NA
GN-2	2C	CF	--	--	--	C	NA	0.89	NA	NA
SM-17	BC+1[A]	--	--	BC	--	B	NA	0.89	0.89	0.89
SM-7	B	--	--	--	--	--	NA	0.87	NA	NA
SM-5	3[A]	--	--	2[A]	--	1[A]	NA	0.88	0.88	0.88
SM-9	10[A,B]	8[A,B]	6[A,B]	4[A,B]	2[A,B]	1[A,B]	NA	0.86	0.86	0.86
SM-3	10[A]	8[A]	6[A]	4[A]	2[A]	1[A]	NA	0.87	0.87	0.87
GN-3	2(C,F)2G	--	1(C,F)2G	2(C,F)G	--	1(C,F)G	NA	0.89	0.89	NA
FM-6	4(C,F)	--	--	3(C,F)	--	2(C,F)	NA	0.86	NA	NA
FC-2	3[A,B]	--	--	2[A,B]	--	1[A,B]	NA	0.89	0.89	0.89
FM-12	3[A,H,S]	--	--	2[A,H,S]	--	1[A,H,S]	NA	0.80	0.80	0.80
FC-3	3[A,B]	--	--	2[A,B]	--	1[A,B]	NA	0.89	0.89	0.89
GN-7	6[A,B,S]	5[A,B,S]	4[A,B,S]	3[A,B,S]	--	2[A,B,S]	NA	0.88	0.88	0.88
SM-14	B+1[A]	--	--	--	--	--	NA	0.89	0.89	0.89
FC-4	3(C,F)	--	--	2(C,F)	--	1(C,F)	NA	0.88	NA	NA
FM-15	3[A,E,H,S]	--	--	--	--	2[A,E,H,S]	NA	0.87	0.87	0.87
PP-3	2[A,B]	--	--	--	--	1[A,B]	NA	0.86	0.86	0.86
HF-2	10[A,B]*	8[A,B]*	6[A,B]*	4[A,B]*	2[A,B]*	1[A,B]*	NA	0.86	0.86	0.86
SM-10	10[A,B]	8[A,B]	6[A,B]	4[A,B]	2[A,B]	1[A,B]	NA	0.86	0.86	0.86
SM-12	3H	--	2H	H	--	G	NA	NA	0.88	0.88
PP-2	2[A]	--	--	--	--	1[A]	NA	0.85	0.85	0.85
SM-13	6[A]	5[A]	--	4[A]	3[A]	2[A]	NA	0.85	0.85	0.85
PP-1	2(all)	--	--	--	--	1(all)	0.85	0.85	0.85	0.85
SM-11	3(C,F)	--	--	2(C,F)	--	1(C,F)	NA	0.88	NA	NA
SM-16	2C	CF	2F	--	--	1(C,F)	NA	0.87	NA	NA
AV-2	1[A]	--	--	--	--	--	NA	0.89	0.89	0.89
HF-1	3[A,B,S]	--	--	2[A,B,S]	--	1[A,B,S]	NA	0.89	0.89	0.89
FM-16	8(C,D,F,I)	6(C,D,F,I)	5(C,D,F,I)	4(C,D,F,I)	3(C,D,F,I)	2(C,D,F,I)	NA	0.87	NA	NA
SM-15	D	--	--	I[A,B,D,I,H]	--	--	NA	0.85	0.85	0.85
FM-9	2J2K	J2K	--	2JK	--	JK	NA	NA	NA	0.82
AV-1	1[A]	--	--	--	--	--	NA	0.87	0.87	0.87
FM-18	1[A]	--	--	--	--	--	NA	0.83	0.83	0.83
SM-18	1[A,B]	--	--	--	--	--	NA	0.75	0.75	0.75
FM-19	2S	--	--	--	--	S	NA	NA	NA	0.85
PP-6	B	--	--	--	--	--	NA	0.89	NA	NA
SM-19	C+3[A,B]	--	--	--	--	C+2[A,B]	NA	0.88	0.88	0.88
EV-1	B+2[A,B]	--	--	--	--	B+1[A,B]	NA	0.87	0.87	0.87
FM-1	B	--	--	--	--	--	NA	0.94	NA	NA
FM-20	All[A]	--	--	--	--	--	NA	0.89	0.89	0.89
BL-4	BC	--	--	--	--	--	NA	0.90	NA	NA
BL-10	A	--	--	--	--	--	0.87	NA	NA	NA
BL-11	C+1[A,B]	--	--	--	--	C	NA	0.89	0.89	0.89

NOTES: *Required on 1st manned flight R = flight of refurbished entry vehicle [ ] Except entry conditions in bracket
N( ) = any combination of entry condition in parentheses for N flights

Total research value for a set of tasks loaded on an entry vehicle for a given flight plan is ΣV_j over j research tasks.

4. Flight Loading Constraints

It was found that many of the 52 research tasks were uniquely related by their requirement for prerequisite tasks, by requirements for complementary tasks (load with) or by the requirement to exclude certain task pairs (do not load with). Each task was examined for such constraints; table 4 lists the three constraining relationships for the 52 candidate tasks. These constraints were applied as each research task was loaded and were satisfied for the whole set of research tasks loaded on a flight plan.

B. FLIGHT PLAN SELECTION

The flight plan, in terms of entry conditions flown and the number of repetitions of each selected condition, is one of the major variables in the flight loading and research value analysis. Each research task value is dependent upon assignment to specific entry conditions defined in Part II and summarized in table 5. Clearly, the dependence of potential program value upon the selected sequence of flight entry conditions emphasizes the importance of selecting proper sequences for study. The sequence must include repetition in addition to multiplicity of conditions. In many instances, a small increase in the number of flights to which a given task is assigned will significantly increase the research value accrued. The assembly of a set of flight entry conditions is constrained by a set of prerequisites summarized below Clearly, the A and B conditions, representing unmanned flights, must precede all others. Additionally, the condition A, high velocity and altitude abort demonstration, is constrained to precede condition B, systems demonstration and heat shield qualification, because of the priority on crew safety and the simpler mission profile of condition A.

Flight condition	Prerequisite conditions
A	None
B	A
C	A, B
D	A, B, C
E	A, B, C, D
F	A, B, C
G	A, B, C, F
H	A, B, C
I	A, B, C
S	A, B, C, D

TABLE 4
FLIGHT LOADING CONSTRAINTS

Rank	Research task	Load with	Do not load with	Prerequisite
1	SM-1	FM-8		
2	FM-8	FM-7		
3	FM-3			
4	FM-2			
5	FM-7			
6	FM-4	FM-3		(3) FM-3
7	GN-4			(1) GN-2
8	GN-5	GN-4	GN-1, GN-2	
9	FM-13	FM-2		
10	GN-1			
11	EV-2	SM-8		
12	FC-1			
13	FM-5			(3) FM-3
14	SM-6			
15	SM-2			(1) SM-1
16	SM-8			
17	FM-17			
18	GN-6	GN-4		(1) GN-2
19	FM-14	FM-2		
20	GN-2			(1) GN-1
21	SM-17			
22	SM-7			
23	SM-5			
24	SM-9			(1) SM-1
25	SM-3			(1) SM-1
26	GN-3	GN-4		
27	FM-6			(3) FM-3
28	FC-2		FC-1	(4) FC-1
29	FM-12			
30	FC-3		FC-2	(3) FC-1
31	GN-7			(1) GN-1
32	SM-14			
33	FC-4		FC-2	(4) FC-1
34	FM-15			
35	PP-3			
36	HF-2			
37	SM-10	SM-9		
38	SM-12	Any(2) SM-9		
39	PP-2			(4) FC-1
40	SM-13			
41	PP-1			
42	SM-11	SM-9		
43	SM-16			
44	AV-2			
45	HF-1			Any(5) except A, B
46	FM-16			
47	SM-15			
48	FM-9			
49	AV-1			
50	FM-18			(4) FC-1
51	SM-18			(4) FC-1
52	RM-19			(4) FC-1
Base-line tasks	PP-6			
	SM-19			
	EV-1			
	FM-1			
	FM-20			
	BL-4			
	BL-10			
	BL-11			

Values in parentheses indicate number of flights in which experiment is loaded.

TABLE 5

FLIGHT CONDITION SUMMARY--FINAL GUIDANCE SCHEME

Flight condition	Description of flight	Entry conditions						Approximate entry conditions												Launch and orbit data			
		Inertial velocity		Entry angle,	%,[b] $L/D_{max.}$	Bank angle,	Crew status	Crossrange		Downrange		Entry time,	$q_{max.}$		$n_{T_{max.}}$	Q_{tot} [a]		$\dot{q}_{s_{max.}}$ [a]		Number of orbits	Launch azimuth,	Orbit altitude	
		fps	m/sec	deg		deg		n. mi.	km	n. mi.	km	sec	psf	kN/m^2	g	Btu/ft^2	GJ/m^2	Btu/ft^2-sec	Mw/m^2		deg	n. mi.	km
A	Special launch abort--high airload condition	14 756	4498	-4.6	min.	0	Not manned	0	0	800	1 482	700	1200	57.5	6.0	6 000	.068	100	1.13	Special suborbital launch using Eastern Test Range			
B[e]	Heat shield qualification, high total heating	25 860	7982	-1.5	(d)	0	Not manned	0	0	6720	12 420	2379	382	18.3	1.42	108 000	.123	134	1.52	3	65.8	80/200	22.4/61.1
C	Nominal entry				(d)	0	Manned	0	0	5470	10 130	2012	384	18.4	1.38	86 000	.098	46.5	.53	3	65.8		
D[e]	High heating, long entry time				(d)	0		0	0	6720	12 420	2379	382	18.3	1.42	108 000	.123	134	1.52	3	65.8		
E	Maximum heating, maximum downrange				approach 100	0		0	0	6750	12 420	2740	200	9.6	1.40	136 000	.155	128	1.45	3	65.8		
F	Medium crossrange				75	12.5		250	463	4600	8 520	1830	360	17.3	1.60	73 000	.083	100	1.13	2	65.8		
G	High crossrange				(d)	(d)		645	1185	3800	7 040	1578	382	18.3	1.58	88 600	.100	177	2.01	1	77.7		
H	Maximum heating rate, maximum air loads, minimum downrange				approach 100	±75 (reverse roll modulate)		0	0	2250	4 170	1350	550	26.4	3.60	77 000	.088	195	2.22	3	65.8		
I	High airloads, small downrange	25 860	7982	-1.5	min.	±45 (reverse roll modulate)		0	0	3200	5 930	1300	380	18.2	2.00	58 000	.066	110	1.25	3	65.8		
K	Supercircular, high heating rate[c]	30 000	9144	-6.0	max.	0	Manned	0	0	2280	4 220	1620	425	20.4	3.50	86 000	.098	440	5.00	3	65.8	80/200	22.4/61.1
S	Synergetic maneuver	approx 25 900		approx -1.0	Enter with 60° bank angle at $L/D_{max.}$ Increase to $C_{L_{max.}}$ when heading changes by 2°. Entry vehicle will skip, then make nominal entry.																		

(a) Based on a nose radius of 1 foot (0.305 m)

(b) Hypersonic viscous value. Specific experiments require modulation around this L/D

(c) Data are for roll modulated constant altitude entries

(d) See Part V, Section B.2 of this report for details

(e) These flight conditions identical except that B condition is unmanned flight.

Entry condition C, the nominal entry (manned), is designated as a prerequisite to all other types of manned flight conditions. Also, high heating condition D will precede the maximum heating condition E, and medium crossrange condition F must be demonstrated before attempting the maximum crossrange condition G. Because of the high total heating involved in the synergetic maneuver (condition S), flight condition D is established as a prerequisite.

The number of flights assigned to each flight condition (repetition) within a given flight program size (total number of flights) has been derived by examination of the intrinsic value and informational value of research tasks associated with each entry condition. No additional informational value is given for more than one A and one B entry condition. Therefore, only one A and one B condition are planned. Flight condition C is a prerequisite for all other manned flights so at least one C condition flight is necessary. Conditions F and G are required for many high value research tasks and are assigned to the smallest flight program. (The larger flight plans can accommodate flight conditions linked to lower research tasks.) Combinations of entry conditions were selected to yield the highest ultimate research value.

Flight plans constructed for a range of 4 to 22 flights are shown in table 6 and are the basis for flight plan size tradeoffs. The 5-, 7-, 11-, and 15-flight plans were specifically selected from this listing for research value analysis.

TABLE 6

FLIGHT PLANNING SELECTION CHART

Number of flights	Entry condition									
	A	B	C	D	E	F	G	H	I	S
4	1	1	1			1				
5	1	1	2			1	1			
6	1	1	1			1	1			
7	1	1	2			2	1			
8	1	1	2			2	1		1	
9	1	1	2			2	2		1	
10	1	1	2			3	2		1	
11	1	1	2			3	3		1	
12	1	1	2			3	3		2	
13	1	1	2	1		3	3		2	
14	1	1	2	1		3	3	1	2	
15	1	1	2	1		3	3	1	2	
16	1	1	2	1		3	3	2	2	1
17	1	1	2	1		3	3	2	2	1
18	1	1	2	1		3	3	2	2	2
19	1	1	2	1		4	3	2	2	2
20	1	1	3	1		4	3	2	3	2
21	1	1	3	1		4	4	2	3	2
22	1	1	3	1		4	4	3	3	2

C. CANDIDATE SYSTEMS

Evaluation of HL-10 research value and cost as a function of size was predicated upon five vehicle designs sized for full crew complements of 1, 2, 4, 6, and 8 men. These vehicles were designated A, B, C, D, and E, respectively, and considered for both full and reduced crew complements.

Two resources were previously reported as constraints in the research task assignment. The quantitative availability of these resources in each candidate design is indicated in table 7.

TABLE 7

CANDIDATE DESIGN RESOURCES

Crew complement	Weight available for research, lb (kg)					
	Vehicle designation	A	B	C	D	E
	Full crew complement	1	2	4	6	8
1		170 (77)	645 (292)	1530 (694)	1665 (755)	1620 (735)
2		-	135 (61)	1020 (462)	1325 (601)	1280 (580)
3		-	-	510 (231)	1075 (487)	1025 (464)
4		-	-	0	811 (368)	750 (340)
5		-	-	-	528 (239)	482 (218)
6		-	-	-	0	240 (109)
7		-	-	-	-	80 (36)
8		-	-	-	-	0

1. Selection of Candidates

It is highly desirable to limit the candidate designs to those entry vehicles in table 8 that will exhibit desirable qualities in the selection analyses. Designs can be excluded because inadequate weight and crew resources are available. Considering that 0.7 of a man second/second is required for the basic tasks, the crew resource for research experiments corresponds to the crew complement reduced by this basic task requirement.

All of the potential A and B size vehicle candidates are included in the analysis. The one-man and full-crew complements in the C and D size vehicles are eliminated due to the disproportionate resources; i.e., on the full-crew complement no research equipment is allowed. The two-man crew complement in the D size vehicle was eliminated for a similar reason. The E size vehicle offers consistently less equipment weight capability than the D size vehicle and, therefore, the three- and five-man crew complements were selected as being representative. The validity of excluding the D size vehicle with a two-man crew complement was subsequently confirmed and is discussed later.

Each candidate design is denoted by a letter and number indicating the vehicle size and crew complement, respectively. Thus, a B/1 designation corresponds to a B size vehicle (full complement of two men) and a crew of one.

III. TECHNIQUES UTILIZED

The research potential of candidate vehicle design and flight plan combinations was evaluated, early in the study, by a manual, analytical technique (heuristic)--later, by a combination of two computer programs. An auxiliary input generator program was used to identify alternative assignments for each task and provide inputs to a flight loading model with linear programming. The heuristic and computer techniques used identical input information: research tasks and intrinsic value, selected flight plans, and candidate entry vehicle/crew combinations.

Cost estimates for vehicle design and flight plan combinations were obtained using the existing Martin Marietta Space Systems Cost Model (SSCOM). When the D/3 vehicle had been selected, the Martin Marietta Coincident Cost Model (COCOM) was used to provide more detailed cost breakdowns.

A. HEURISTIC ANALYSIS

A manual technique of loading research tasks on given flight plans to yield maximum research value was initially developed to provide checkpoints for later automated computation and to gain advance knowledge on tradeoff trends. The research value produced by various combinations of entry vehicle sizes, crew sizes, and flight plans was obtained by this analytical technique. This analysis is termed heuristic since judgment is exercised in fitting tasks within fixed vehicle resources (weight and crew) for highest output.

1. Entry Vehicle Resources Available

Available crew and weight for research are the resources used in the heuristic analysis. These resources, discussed previously, were assigned to 10 vehicle size/crew size combinations. Crew available for research was reduced by 0. 7 to account for basic mission tasks exclusive of research. The resulting weights and crew sizes available for research are given in Table 8.

TABLE 8

RESOURCES AVAILABLE FOR RESEARCH

Vehicle size	Crew	Resources available for research		
		Weight, lb	Weight, kg	Crew
A	1	170	77	0. 3
B	1	645	293	0. 3
	2	135	61	1. 3
C	2	1020	462	1. 0
	3	510	231	2. 3
D	3	1075	487	2. 3
	4	811	368	3. 3
	5	528	240	4. 3
E	3	1025	464	2. 3
	5	482	219	4. 3

2. Analytical Procedure Used

The step-by-step procedure for the heuristic flight loading analysis, illustrated in figure 2, assigned research tasks to specified entry conditions of the flight plan of interest and then loaded these tasks on the vehicle by descending value until weight and/or crew resources were filled. The value, V_{ℓ} (value of ℓth experiment), of the loaded experiments was then summed for each of the 10 vehicle size/crew size candidates to produce the desired set of total research values.

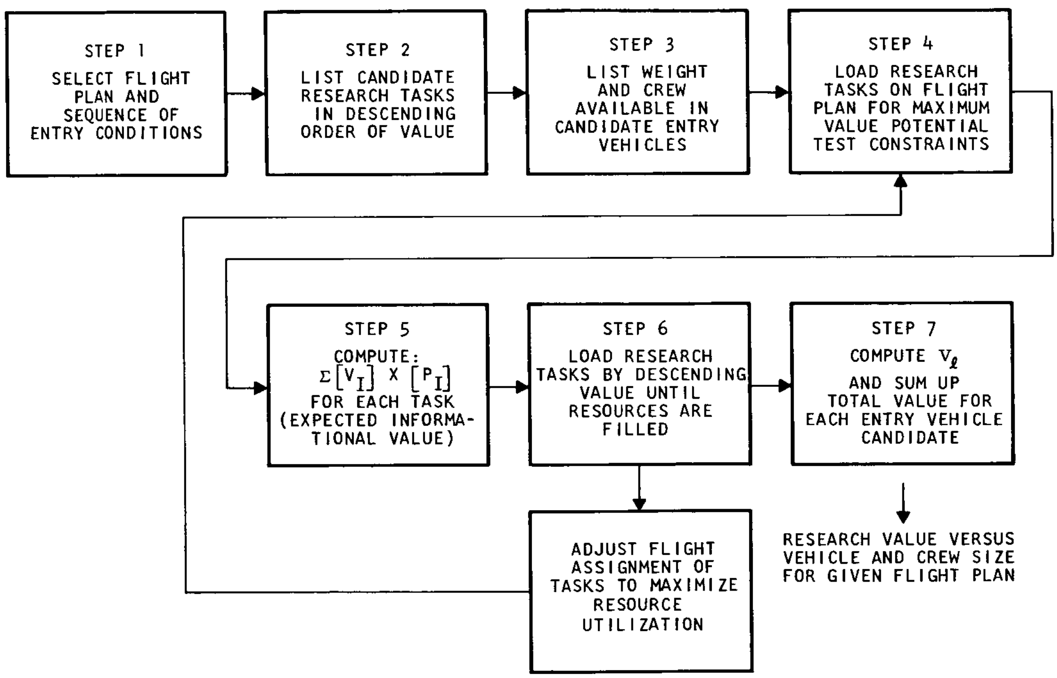

FIGURE 2. PROCEDURE FOR HEURISTIC FLIGHT LOADING ANALYSES

A description of each step of the procedure is related below using a 15-flight program as an example:

<u>Step 1: Select flight plan and sequence of entry conditions.</u>- The sequence of entry conditions for the flight plan was entered as columns of a matrix format as shown in table 9.

<u>Step 2: List candidate research tasks in descending order of value.</u>- Research tasks were listed as rows of the matrix in table 9 in descending order of intrinsic value. This value ranking permitted systematic loading of the research tasks.

Step 3: List weight and crew available in candidate entry vehicles. Research equipment weight and crew size available on each of 10 selected vehicle size/crew size combinations were set up as columns in the right-hand side of the matrix (table 9).

Step 4: Load research tasks on flight plan. - This step required the most extensive judgment of any step in the heuristic analysis. Utilizing the information value versus entry condition chart (table 3) as a guide, research tasks were assigned to appropriate entry conditions. The loading constraints of table 4 were checked as each task was loaded to assure that no constraint was violated. This turns out to be an iterative process for the more complex constraints. Each task loaded in the matrix was entered as (weight/crew) required. As an example, Task FM-7 attains an information value of 0.99 on one B and five total C and F entry conditions. Since this task is not constrained by loading it was assigned to flights 2, 3, 4, 6, 7 and 8 or 1-B, 2-C and 3-F conditions. Task FM-8 is constrained to be conjunctive with Task FM-7, so it was loaded on the same flights of that task. This technique was followed until all tasks were assigned. Where multiple choices were available, the tasks were assigned such that accumulated research weight and crew utilization were more evenly distributed among the flights.

Step 5: Compute $\Sigma [V_I] [P_I]$ for each task. - Truth tables showing all possible combinations of zero, single, double and triple failures were set up for each task and the term P_I was computed by the expression $P_I = P_S^{n-r} (1 - P_S)^r$. The appropriate V_I term was selected from table 3 and the $\Sigma P_I V_I$ term computed. The $\Sigma P_{I_\ell} V_{I_\ell}$ and $V_{0_\ell} \Sigma P_{I_\ell} V_{I_\ell}$ terms were then entered in the last two columns of table 9. The sample computation for Task FM-8 is shown in table 10.

Step 6: Load research tasks by descending value. - The objective of this step is to select a set of research tasks which fits within the weight and crew resource constraints and which yields maximum value V_I. This was accomplished by taking the tasks as loaded by step 5 and, by descending value, reloading them into the weight and crew resources available for each entry vehicle/crew size combination. The first operation was to load all candidate tasks listed in the loading matrix of table 9 which have zero weight and crew requirements. Next, tasks requiring crew and/or weight were loaded. In general, tasks of high value and low resources required were loaded first, and tasks of low value and high resource requirements were loaded last. A final tradeoff was made between flight assignment and resources used in order to obtain better utilization of weight and crew and possibly increase value by permitting the inclusion of one additional experiment.

Step 7: Compute V_ℓ and sum up total value for each entry vehicle. - This step obtained the total research value potential of the 10 candidate vehicle/crew sizes. The $V_{0_\ell} \Sigma P_{I_\ell} V_{I_\ell}$ values for the task checked in the resource

TABLE 9

HEURISTIC ANALYSIS MATRIX FOR 15-FLIGHT PLAN

j	Research task	V_{o_j}	Loading of j th task on flight plan (weight, lb*/crew)															Research task loading for vehicle and crew size combinations and weight resource										Number of flights	
																		A	B		C		D			E		15	
																		1	1	2	2	3	3	4	5	3	5	$\sum P_{I_\ell} V_{I_\ell}$	$V_{o_\ell} \sum P_{I_\ell} V_{I_\ell}$
			A	B	C	C	D	F	F	F	G	G	G	H	I	I	S	170	645	135	1020	510	1075	811	528	1025	482		
1	SM-1	244.9		0/0	0/0	0/0												X	X	X	X	X	X	X	X	X	X	.713	175
2	FM-8	223.3		20/0	20/0	20/0		20/0	20/0	20/0								X	X	X	X	X	X	X	X	X	X	.660	147
3	FM-3	223.3			0/.4	0/.4	0/.4	0/.4	0/.4	0/.4	0/.4	0/.4	0/.4	0/.4	0/.4	0/.4				X	X	X	X	X	X	X	X	.716	159
4	FM-2	222.1			0/0	0/.5	0/.5	0/.5	0/.5	0/.5										X	X	X	X	X	X	X	X	.697	155
5	FM-7	191.6		0/0	0/0	0/0		0/0	0/0	0/0								X	X	X	X	X	X	X	X	X	X	.778	149
6	FM-5	145.0						0/0	0/0	0/0	0/0	0/0	0/0					X	X	X	X	X	X	X	X	X	X	.732	106
7	GN-4	152.2						100/0	100/0	100/0	100/0	100/0	100/0					X	X		X	X	X	X	X	X	X	.723	110
8	FM-4	154.1						0/0	0/0	0/0	0/0	0/0	0/0					X	X	X	X	X	X	X	X	X	X	.683	105
9	GN-5	150.3					100/.8			100/.8	100/.8	100/.8										X	X	X	X	X	X	.488	73
10	FM-13	146.9			0/0	0/0	0/0	0/0	0/0	0/0								X	X	X	X	X	X	X	X	X	X	.638	94
11	EV-2	146.5					0/0		0/0	0/0	0/0	0/0	0/0	0/0	0/0		0/0	X	X	X	X	X	X	X	X	X	X	.727	106
12	SM-6	128.9		50/0	50/.1	50/.1		50/.1	50/.1										X	X		X	X	X	X	X	X	.601	77
13	GN-1	146.7			0/.3	0/.3		0/.3	0/.3				0/.3							X	X	X	X	X	X	X	X	.516	76
14	FC-1	145.2			0/.2	0/.2	0/.2	0/.2					0/.2	0/.2		0/.2		X	X			X	X	X	X	X	X	.372	54
15	SM-2	128.1			0/0	0/0		0/0	0/0	0/0								X	X	X	X	X	X	X	X	X	X	.675	86
16	FM-17	123.2				0/0		0/0	0/0	0/0					0/0	0/0		X	X	X	X	X	X	X	X	X	X	.623	77
17	SM-8	124.1					0/0		0/0	0/0	0/0	0/0	0/0	0/0	0/0		0/0	X	X	X	X	X	X	X	X	X	X	.708	88
18	GN-6	108.4						75/0	75/0	75/0	75/0	75/0							X		X	X	X	X	X	X	X	.752	81
19	FM-14	102.1			0/0	0/0	0/0	0/0	0/0	0/0								X	X	X	X	X	X	X	X	X	X	.676	69
20	SM-7	86.0		0/0														X	X	X	X	X	X	X	X	X	X	.740	64
21	FM-6	79.2						250/.4	250/.4														X	X		X		.234	18
22	FM-12	74.2			0/0	0/0	0/0	0/0										X	X	X	X	X	X	X	X	X	X	.631	47
23	GN-2	90.8				0/0		0/0	0/0									X	X	X	X	X	X	X	X	X	X	.653	59
24	SM-5	85.5		10/0	10/0	10/0	10/0											X	X	X	X	X	X	X	X	X	X	.805	69
25	SM-17	86.4		0/0	0/0	0/0	0/0											X	X	X	X	X	X	X	X	X	X	.744	64
26	SM-3	81.1			10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0				X	X	X	X	X	X	X	X	X	X	.686	56

TABLE 9. --Concluded

HEURISTIC ANALYSIS MATRIX FOR 15-FLIGHT PLAN

j	Research task	V_{o_j}	Loading of j th task on flight plan (weight, lb*/crew): A	B	C	C	D	F	F	F	G	G	G	H	I	I	S	Research task loading for vehicle and crew size combinations and weight resource: A 1 170	B 1 645	B 2 135	C 2 1020	C 3 510	D 3 1075	D 4 811	D 5 528	E 3 1025	E 5 482	Number of flights 15: $\sum P_{I_\ell} V_{I_\ell}$	$V_{o_\ell} \sum P_{I_\ell} V_{I_\ell}$
27	SM-9	81.6			10/0	10/0	10/0	10/0	10/0	10/0	10/0	10/0						X	X	X	X	X	X	X	X	X	X	.673	55
28	FC-2	75.0									0/.7	0/.7			0/.7			X	X	X	X	X	X	X	X	X	X	.762	50
29	GN-3	79.6						50/0	50/0	50/0	50/0	50/0	50/0						X		X	X	X	X	X	X	X	.657	52
30	FC-3	70.9						70/.1	70/.1	70/.1			70/.1									X	X	X	X	X	X	.776	55
31	FM-15	63.2				15/0	15/0	15/0	15/0	15/0								X	X	X	X	X	X	X	X	X	X	.647	41
32	PP-3	62.7												150/.4	150/.4	150/.4					X	X	X	X	X	X	X	.691	43
33	PP-2	62.7								0/.3	0/.3	0/.3								X	X	X	X	X	X	X	X	.575	36
34	GN-7	65.6				50/0	50/0				50/0	50/0	50/0	50/0					X		X	X	X	X	X	X	X	.647	42
35	SM-14	63.5		35/0	35/0	35/0												X	X		X	X	X	X	X	X	X	.748	48
36	HF-2	56.7			20/0	20/0	20/0	20/0	20/0	20/0	20/0	20/0	20/0	20/0				X	X	X	X	X	X	X	X	X	X	.717	41
37	FC-4	63.5							200/.1	200/.1									X				X			X		.488	31
38	SM-10	55.9			0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0						X	X	X	X	X	X	X	X	X	X	.670	37
39	SM-12	55.7									0/0	0/0						X	X	X	X	X	X	X	X	X	X	.313	17
40	SM-13	44.6				0/0	0/0	0/0	0/0	0/0	0/0	0/0						X	X	X	X	X	X	X	X	X	X	.642	29
41	PP-1	43.4			0/0	0/0	0/0	0/0										X	X	X	X	X	X	X	X	X	X	.706	31
42	SM-16	34.5			0/0	0/0		0/0	0/0									X	X	X	X	X	X	X	X	X	X	.711	25
43	AV-2	33.1						40/.2	40/.2													X	X	X	X	X	X	.893	29
44	SM-11	40.0			125/.2	125/.2	125/.2	125/.2	125/.2	125/.2	125/.2	125/.2																0	0
45	HF-1	31.9											0/0	0/0	0/0	0/0		X	X	X	X	X	X	X	X	X	X	.745	24
46	FM-16	27.4			40/0	40/0	40/0	40/0	40/0	40/0					40/0	40/0			X		X	X	X	X	X	X		.647	20
47	SM-15	22.7					100/.8	100/.8	100/.8																			0	0
48	FM-9	20.1																										0	0
49	FM-18	12.5											200/.5	200/.5	200/.5	200/.5					X	X	X	X	X	X	X	.657	8
50	AV-1	14.7		0/0	0/0	0/0	0/0											X	X	X	X	X	X	X	X	X	X	.712	10
51	FM-19	1.0															0/0	X	X	X	X	X	X	X	X	X	X	.577	1
52	SM-18	5.0									300/0	300/0							X		X		X	X		X		.464	2
																	V_{total}	2135	2440	2426	2732	2441	2992	2992	2941	2992	2921		

* For metric equivalents see table 11

TABLE 10

SAMPLE COMPUTATION OF $\Sigma V_{I_\ell} P_{I_\ell}$ FOR RESEARCH TASK FM-8

Loading	Research task FM-8															Computation of		
	A	B	C	C	D	F	F	F	G	G	G	H	I	I	S	$\left[P_{I_\ell}\right]$	$\left[V_{I_\ell}\right]$	$V_{I_\ell} P_{I_\ell}$
		√	√	√		√	√	√										
Truth table	x	x	x	x		x	x	x	(all successes)							$(0.85)^7$	(0.99)	0.317
x = success	x	x	o	x		x	x	x	single failures							$(5)(0.85)^6(0.15)$	(0.94)	0.263
o = failure	x	x	x	o		x	x	x										
	x	x	x	x		o	x	x										
	x	x	x	x		x	o	x										
	x	x	x	x		x	x	o										
	x	x	o	x		o	x	x	double failures							$(9)(0.85)^5(0.15)^2$	(0.85)	0.076
	x	x	o	x		x	o	x										
	x	x	o	x		x	x	o										
	x	x	x	o		o	x	x										
	x	x	x	o		x	o	x										
	x	x	x	o		x	x	o										
	x	x	x	x		o	o	x										
	x	x	x	x		o	x	o										
	x	x	x	x		x	o	o										
	x	x	o	x		o	o	x	triple failures							$(6)(0.85)^4(0.15)^3$	0.45	0.004
	x	x	o	x		o	x	o										
	x	x	o	x		x	o	o										
	x	x	x	o		o	o	x										
	x	x	x	o		x	o	o										
	x	x	x	x		o	o	o										
																		0.660

loading matrix (right-hand side of table 9) were summed for each vehicle/crew size combination and entered at the bottom of the resource loading matrix.

Total resources utilized for the research tasks loaded on the 15-flight plan are shown in table 11.

B. INPUT GENERATOR PROGRAM

Mechanization of the flight loading model discussed later maximizes the potential research value by assignment of alternative tasks. In order to achieve a true maximum, all alternative assignments must be identified for each task. Manual identification of all alternatives would be a formidable undertaking; e.g., an 11-flight program input to the computerized flight loading model consists of 5655 identified alternative assignments. To ensure identification of each alternative assignment, eliminate errors, and reduce the evaluation time, an auxiliary computer program was prepared to generate input data for the flight loading model.

1. Generator Program Inputs

This input generator program utilizes two categories of information: one involves data contained in the source program, the second comprises data entered at time of execution. These data inputs, which are defined in detail in section II, are summarized below:

Source program data

- Research task intrinsic value
- Research task concurrence constraints
- Research task prerequisite constraints
- Research task exclusion constraints
- Entry vehicle resource definition

Execution data

- Research task information value
- Research task success probability
- Research task source definition
- Flight program definition

2. Generator Program Outputs

The output of this generator program is a binary coded decimal (BCD) tape, which is used directly as the input to the CEIR LP90/94 code of the flight loading model. The tape, written in FORTRAN card image format, has three specific parts: row identification, matrix elements and right-hand side as follows:

TABLE 11

WEIGHT AND CREW UTILIZED FOR 15-FLIGHT PLAN D/3 VEHICLE

Research task	15-flight plan														
	A	B	C	C	D	F	F	F	G	G	G	H	I	I	S
FM-8		20(9)/0*	20(9)/0	20(9)/0		20(9)/0	20(9)/0	20(9)/0							
FM-3			0/0.4	0/0.4	0/0.4	0/0.4	0/0.4	0/0.4	0/0.4	0/0.4	0/0.4	0/0.4	0/0.4		
FM-2				0/0.5	0/0.5	0/0.5	0/0.5	0/0.5							
SM-6		50(23)/0	50(23)/0.1	50(23)/0.1		50(23)/0.1	50(23)/0.1								
GN-1			0/0.3	0/0.3		0/0.3	0/0.3				0/0.3				
SM-5		10(5)/0	10(5)/0	10(5)/0	10(5)/0										
SM-3			10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0			
SM-9			10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0	10(5)/0					
FM-15				15(7)/0	15(7)/0	15(7)/0	15(7)/0	15(7)/0							
FC-2									0/0.1	0/0.1			0/0.1		
PP-2								0/0.3	0/0.3	0/0.3					
HF-2			20(9)/0	20(9)/0	20(9)/0	20(9)/0	20(9)/0	20(9)/0	20(9)/0	20(9)/0	20(9)/0	20(9)/0			
GN-4						100(45)/0	100(45)/0	100(45)/0	100(45)/0	100(45)/0	100(45)/0				
GN-5					100(45)/0.8			100(45)/0.8	100(45)/0.8	100(45)/0.8					
FC-1			0/0.2	0/0.2	0/0.2	0/0.2					0/0.2	0/0.2		0/0.2	
GN-6						75(34)/0	75(34)/0	75(34)/0	75(34)/0	75(34)/0					
GN-3						50(23)/0	50(23)/0	50(23)/0	50(23)/0	50(23)/0	50(23)/0				
SM-14		35(16)/0	35(16)/0	35(16)/0											
PP-3												150(68)/0	150(68)/0	150(68)/0	
AV-2						40(18)/0.2	40(18)/0.2								
FM-16			40(18)/0	40(18)/0	40(18)/0	40(18)/0	40(18)/0	40(18)/0					40(18)/0	40(18)/0	
FM-18											200(91)/0.5	200(91)/0.5	200(91)/0.5	200(91)/0.5	
FM-6						250(113)/0.4	250(113)/0.4								
FC-4							200(91)/0.1	200(91)/0.1							
SM-18									300(136)/0	300(136)/0					
Total		115(52)/0	195(88)/1.0	260(118)/1.5	255(116)/1.9	750(340)/2.2	950(431)/2.1	710(322)/2.2	705(319)/1.6	665(301)/1.6	700(317)/2.0	580(263)/2.0	590(268)/1.9	590(268)/1.6	

* Weight, lb (kg)/crew, man sec/sec--D/3 vehicle resources 1075 lb (487 kg); 2.3 men (0.7 crew required for basic flight tasks)

Row identification

- Nature of constraints

Matrix elements

- Alternative assignments
- Loading constraints
- Resource requirements

Right-hand side

- Entry vehicle capability

3. General Description

The input generator program has been written principally in FORTRAN IV language with about five percent of instructions in Machine Assembly Program (MAP) language. The logic employed to develop the input data of 52 entry research tasks into alternative task assignment and associated characteristics is depicted in figure 3.

Objective value. - The objective value of each identified alternative is the potential research value accumulated by assigning that alternative in the flight loading model solution. The objective value (total research task value V_ℓ) is derived in accordance with actual flight test considerations. The functions relating to determination of the total value (OBJ) of an experiment are shaded in figure 3.

Truth table. - Each input flight program definition includes a flight pattern or sequential definition of the entry conditions to be flown. From the given flight pattern, a truth table and information table are developed. The truth table is a table of all failure/success patterns to be considered. An information table is developed from the truth table by assigning failure to all flights where prerequisite conditions (table 6) are not satisfied.

Probabilistic table. - A probabilistic table is developed from the truth table and experiment probability of achieving value. This table indicates the probability of each failure pattern in the truth table occurring in recognition of the success probability of the experiment on one flight (P_S) and the failure probability ($1 - P_S$). The products of each row become the column vector $[P_I]$, probability of acquiring research information.

Matched pattern. - The matched pattern is one of many assignment patterns for an experiment on a sequence of flights of different entry conditions. Each pattern has a corresponding informational value, V_I.

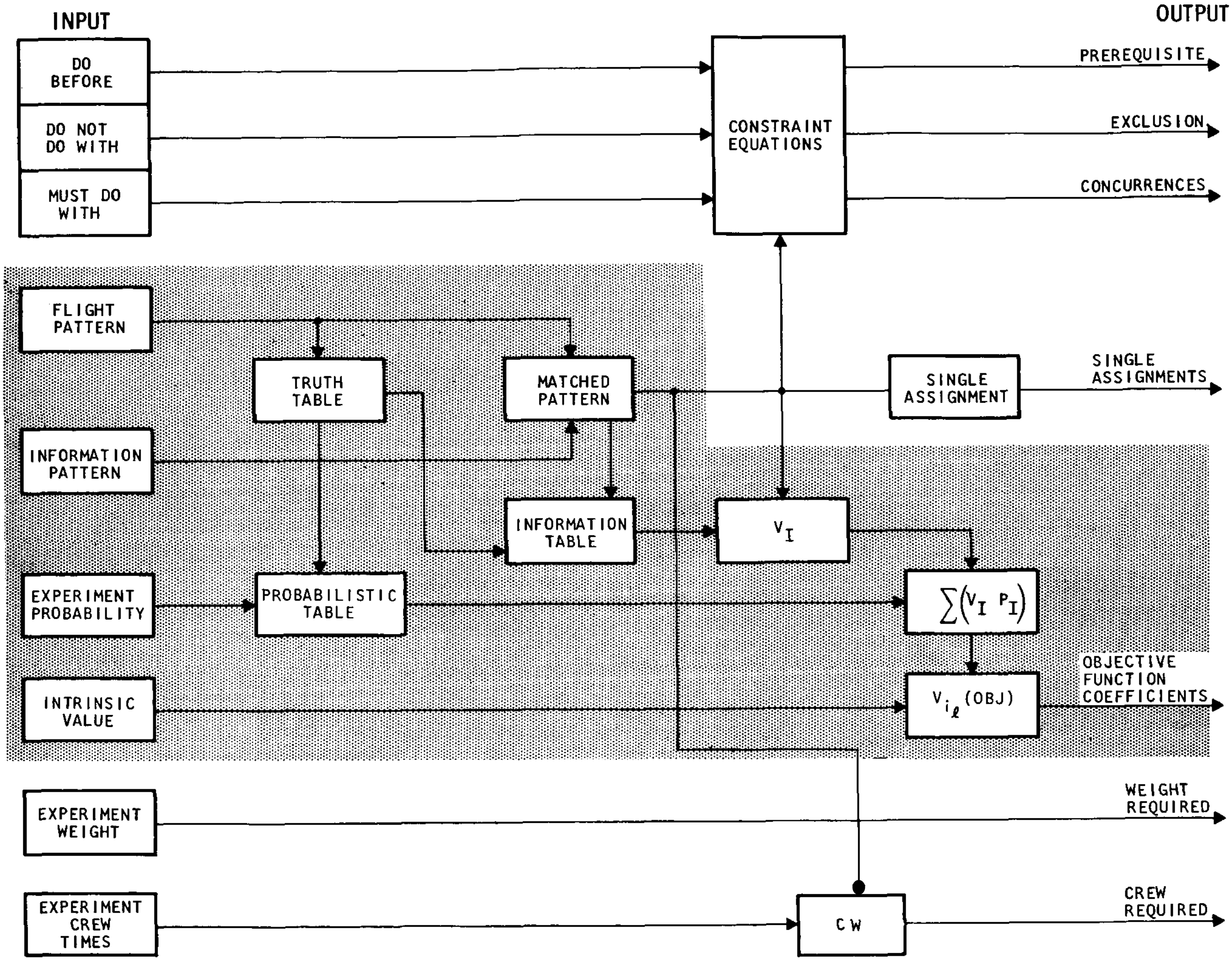

FIGURE 3. INPUT GENERATOR LOGIC

Informational table. - The informational table as obtained from match patterns is compared to generate a column vector $\left[V_I\right]$ corresponding to the truth table failure/success patterns. Each row in the column vector is the informational value (V_I) acquired when the assigned task is subject to the related failure/success pattern.

Constraints. - The other matrix elements developed by the input generator are directly related to the input data for each alternative assignment. These elements constitute the coefficients in the flight loading model equation discussed in the next subsection.

4. Features

The generator program is available for a very specific application, but considerable versatility does exist with the application. These capabilities are summarized below:

- 6 Alternative assignment designations
- 52 Research tasks
- 9 Different entry conditions
- 25 Total flights

5. Subroutines

The generator program has been compiled and executed on the IBM Model 7094 computer and designated MB-022. Six subroutines have been written to complement the mainline program. Three of these relate to tape allocation and assignment of tabular data. The remaining three are related to the assignment of tasks to flights:

(1) Number of alternatives within the available entry conditions and the required entry conditions.

(2) Binary pattern analysis and determination of number of positions in a given state.

(3) Binary pattern analysis and determination of the specific positions in a given state.

C. FLIGHT LOADING MODEL

The flight loading model is a technique for determining the optimum potential research capability of any candidate lifting body design in a specified series of entry condition flights. The model is in standard linear programming format. There is an objective function, Z, in linear form, to be maximized subject to a set of "m" linear constraints written as equalities or inequalities. The sense of the inequality is, of course, determined by the nature of the constraint.

This model was developed to establish the potential research effectiveness, or worth, of each candidate design in each specific flight program. In this way, data can be developed that shows: (1) the influence of vehicle and crew size on the capability to perform research, and (2) the size vehicle and the type flight plan that provide the means for performing the most research.

The model was implemented with the CEIR Corporation (Alexandria, Va.) Linear Programming Code LP90/94.

1. Formulation

The flight loading model formulation required selection of a meaningful objective function and identification of reasonable real life constraints. Three objectives were considered: (1) maximize the resource utilization, (2) maximize the number of research tasks assigned, and (3) maximize the value of research accomplished. Maximizing the resource utilization was rejected because it would minimize growth potential which was an attribute for the selected design. Further, maximizing resource utilization would not necessarily result in the selection of high valued tasks over lesser valued ones in the loading analysis. Maximizing the number of research tasks loaded could possibly result in the situation where large numbers of very low valued tasks are assigned in lieu of all high value research.

The third objective above was selected because data of the form "value of research accomplished" was of the most use in size and program selection studies. In addition, this objective would tend to accomplish the objectives of the other two functions considered since additional research tasks are assigned until the resource remaining is inadequate for further task assignment.

The linear programming format maximizes the objective function subject to established constraints. Six types of constraints were recognized. The first type of constraint, unique assignment, was required to ensure that artificial value was not accumulated by assigning a task twice to any given flight. The second and third types of constraint ensured that the crew and weight resources required by assigned experiments did not exceed the system capability. The fourth, fifth and sixth types of constraint concerned the compatibility of each unique pair of experiments. These constraints ensure proper assignment of prerequisite, complementary and contradictory tasks.

2. Equations

The model is composed of several equations, and the linear program is a technique for simultaneous solution of these equations. The equations required to implement formulation of the flight loading model are identified in the following discussion.

An objective function, Z, is maximized, subject to a set of constraints:

$$Z = \sum_i \sum_\ell V_{i\ell} \, x_{i\ell}$$

where $V_{i\ell}$ is a number which represents the research value of task i in its ℓth assignment, and $x_{i\ell}$ designates the ℓth assignment of task i and has a value of either zero (if not assigned) or one (if assigned).

The summation of values over all tasks and assignments yields the total program value Z. This total value is then maximized.

The resource constraint equations

$$\sum_{\ell} \sum_{i} r_{ij\ell w} \, x_{i\ell} \leq R_{jw}$$

$$\sum_{\ell} \sum_{i} r_{ij\ell c} \, x_{i\ell} \leq R_{jc}$$

where

$r_{ij\ell w}$ = weight of task i in its ℓth assignment on flight j

$r_{ij\ell c}$ = crew required by task i in its ℓth assignment on flight j

R_{jw} = total weight available for tasks on flight j

R_{jc} = total crew available for tasks on flight j

require that all tasks assigned to each flight use no more than the weight and crew resources (R_{jw} and R_{jc}) available for that flight.

The single assignment constraint equation

$$\sum_{i} x_{i\ell} \leq 1$$

permits only one assignment of each task.

The "must" group constraint equations

$$x_{i'\ell} - x_{i\ell} \geq 0$$

$$x_{i'\ell k} - x_{i\ell k} \geq 0$$

where $x_{i\ell k} = x_{i\ell}$ on flight k ensure the simultaneous assignment of two tasks, i and i', when required by the task definitions.

The "must not" group constraint equations

$$x_{i'\ell} + x_{i\ell} \leq 1$$

$$x_{i'\ell k} + x_{i\ell k} \leq 1$$

prevent simultaneous assignment of two incompatible tasks, i and i'.

The prior requirement constraint equations

$$x_{i'\ell} - x_{i\ell} \geq 0$$

$$x_{i'\ell k} - x_{i\ell k} \geq 0$$

ensure that tasks are accomplished in sequence when required to do so by the task definitions. The prior requirement equations have the same form as the "must" group equations.

The objective function, once selected, is written as a linear equation relating each unique assignment with the proper value coefficient. The variable $x_{i\ell}$ represents the "ith" unique assignment of research task ℓ. The $V_{i\ell}$ term is the potential research value of this unique assignment; e.g., if three experiments are considered and four unique assignments are defined for each, the objective equation would be:

$$Z = X_{11}V_{11} + X_{12}V_{12} + X_{13}V_{13} + X_{14}V_{14} + X_{21}V_{21} + X_{22}V_{22} + X_{23}V_{23} + X_{24}V_{24} + X_{31}V_{31} + X_{32}V_{32} + X_{33}V_{33} + X_{34}V_{34}$$

Further, if the solution were $X_{11} = 1$, $X_{23} = 1$, and $X_{32} = 1$ and all other X's were 0, the objective function would equal $V_{11} + V_{23} + V_{32}$.

The resource constraints relate the assigned task weight and crew resource on each flight to the system capability. The term $r_{ij\ell w}$ represents the requirement for specified weight to implement the "ith" assignment of task ℓ on flight j. The $C_{i\ell jw}$ term is likewise for crew resource requirement. There is one weight and one crew equation for each flight in the program being evaluated. The objective function was maximized while the total resource constraints assigned are limited to the entry vehicle capability.

The single assignment constraint equations limit the solution to one unique "i" assignment for each experiment. This is accomplished by writing one equation for each task. If a given task has three alternatives, the equation would be $X_{11} + X_{12} + X_{13} \leq 1$ and thus only one alternative assignment is allowed.

The must group equation ensures assignment of $x_{i\ell' k}$ if $x_{i\ell k}$ is assigned. Here ℓ' designates a task that must be assigned when the task designated ℓ is assigned. The subscript k relates two specific tasks on a specific flight. The must not equation contains the same variables and prevents assignment of two incompatible experiments to the same flight. The prior requirement is of the same form as the must group except the task relationships are concerned with assignment of prerequisite tasks, e.g., the first task ($\ell = 1$) is required to be done with the fourth task ($\ell' = 4$). Two alternates are defined for the first task: assignment on flight 5 ($k = 5$) or assignment on flight 6 ($k = 6$). One assignment on flights 5 and 7 is defined for the fourth task. Three equations would be written:

$$X_{145} - X_{115} \geq 0$$

$$- X_{216} \geq 0$$

$$X_{147} \geq 0$$

It can be seen that X_{14k} is a valid assignment under any circumstances. Assignment X_{12k} is never valid, and assignment X_{11k} is valid if X_{14k} is assigned.

D. SPACE SYSTEM COST MODEL

The Space System Cost Model (SSCOM) was used to estimate program costs for selection of vehicle and program size. SSCOM was developed under Martin Marietta sponsorship to estimate program costs for conceptual space system designs. The model consists of 60 estimating relationships derived from historical cost data on similar space programs.

The SSCOM cost estimates are developed in a "top down" approach. In this technique, significant overall characteristics of a program are used to establish a relationship to similar historical programs. The historical data are mainly in terms of gross program funding and a summary program description; detailed cost estimates are derived deductively. Cost estimating errors due to lack of detailed definition are considered less likely to occur with this technique. However, program cost estimates produced by SSCOM tend to be significantly higher than those estimated at the beginning of a new program by conventional pricing techniques.

SSCOM is particularly well suited to the evaluation of vehicles that have similar functions but vary in size and subsystem complexity.

1. Cost Estimating Relationships

The 60 estimating relationships have been developed using system weight characteristics as the principal cost dependent parameters. The index data were derived from the three United States manned space programs--Apollo, Gemini and Mercury, on which cost data exist in sufficient depth.

The basic cost estimating relationships employed in SSCOM are of the traditional form:

$$C = (c_i)\,(W)\left(\frac{W_i}{W}\right)^{\beta}\,(1 + \alpha)^{y - y_i}$$

where

C = system unit cost of system being evaluated

c_i = reference system unit cost as a function of some characteristic of the system

W = system characteristic upon which cost estimate is based

W_i = reference system cost dependent characteristics

β = exponent for scaling cost dependent characteristic

α = average annual increase in aerospace hardware cost index

y = calendar data of a significant milestone on system being evaluated

y_i = calendar date of similar milestone on index system.

Additional terms are added to account for prior production, learning curves and quantities to be produced.

Significant differences were found to exist between the cost relationships of structural and avionic subsystems. As a result, the structural and avionic costs are estimated in separate relationships and collected for reporting purposes.

All low-value, expendable and ballast weights are excluded from the subsystems. The remaining weight is adjusted to recognize the significant differences in complexity between systems. This adjustment allows the systems cost to be estimated with common relationships in the model.

2. Inputs

The SSCOM estimates are developed from detail system weight statements, the launch vehicle payload capability, 11 characteristics of the flight verification program and 10 items relating to the operational activities. Adjustment of the systems weights is accomplished manually and produces seven summary weight characteristics. The 28 items comprising the computer program input are tabulated in table 12.

3. Outputs

The element grouping used in reporting SSCOM cost estimates is in agreement with the NASA cost reporting structure. Costs are identified as either nonrecurring or recurring. Nonrecurring costs are grouped in three categories: basic analysis, design and development; flight test hardware; flight test operations. Recurring costs are collected in four categories: prime mission hardware; activation; operations and maintenance; replacement procurement.

TABLE 12

SPACE SYSTEM COST MODEL INPUTS

System description:

- Launch vehicle payload capability
- Entry vehicle adjusted subsystem weight
- Entry vehicle adjusted structural weight
- Adapter adjusted subsystem weight
- Adapter adjusted structure weight
- Flight vehicle orbital weight
- Flight vehicle effective launch weight

Flight test program description:

- Entry vehicle quantity
- Adapter quantity
- Aero drop program rocket quantity
- Launch vehicle quantity
- Launch vehicle previous production quantity
- Launch program duration
- Number of launches
- Program go-ahead date
- Aero drop program vehicle quantity
- Aero drop program flight quantity
- Aero drop program duration

Operational program description:

- Initial entry vehicle procurement quantity
- Initial adapter procurement quantity
- Initial launch vehicle procurement quantity
- Launch vehicle previous production quantity
- Operational launch program duration
- Number of entry vehicle refurbishments
- Subsequent entry vehicle procurement quantity
- Subsequent adapter procurement quantity
- Subsequent launch vehicle procurement quantity
- Launch vehicle previous production quantity

In addition, the model reports the first article, last article, and cumulative average unit costs of the orbital vehicle modules for the prime mission hardware. The orbital vehicle can consist of an entry vehicle, adapter, cargo module and velocity module. During the size selection, only entry vehicle and adapter estimating relationships were utilized.

Figure 4 is a cost-o-gram depicting the SSCOM cost estimate for a D/3 size vehicle in an 11-flight research program.

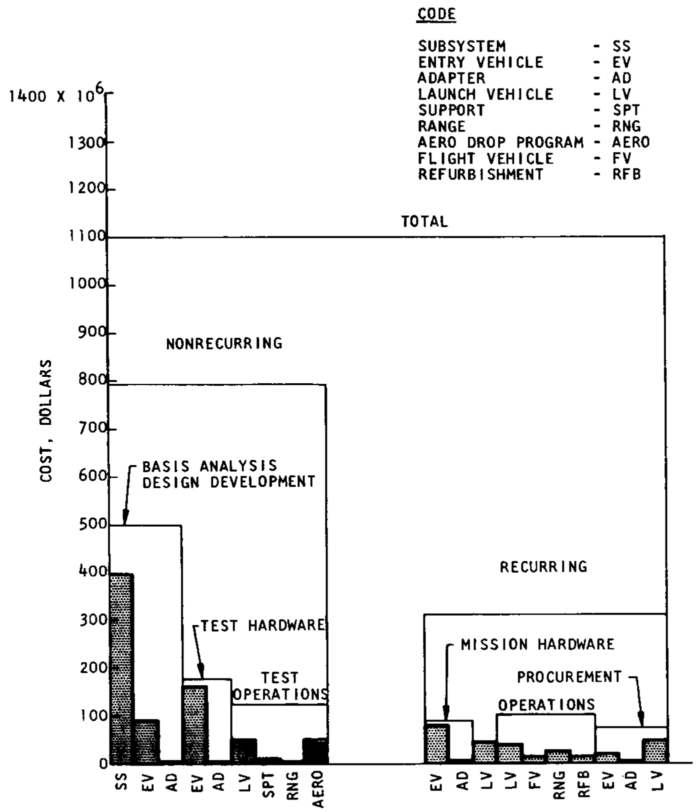

FIGURE 4. SSCOM COST-O-GRAM

E. COINCIDENT COST MODEL

The Coincident Cost Model (COCOM) was used to estimate costs for the recommended flight research program using the selected D/3 vehicle. The change from SSCOM estimating, employed in selection of entry vehicle and crew size and recommendation of flight research programs, was necessary to produce detailed program costs. Introduction of a second cost model was found to be compatible with attributes of the evaluations and models:

(1) The selection study input data were consistent with SSCOM techniques.

(2) The recommended program data were consistent with COCOM techniques.

(3) Several conceptual programs have been evaluated using both models, and the estimates were consistent.

(4) The input data preparation time required for COCOM techniques would have been prohibitive in the selection studies.

The COCOM cost estimates were built up by identifying all contributors to total program cost and establishing cost relationships for each contributor for inclusion in the model. Although this approach differs from the SSCOM technique, the cost relationships for both models are derived from historical programs.

The principal difference, then, is that COCOM estimates include more considerations and produce a significantly more detailed estimate. Specifically, each identifiable subsystem is treated as an independent cost contributor in the COCOM.

1. Cost Estimating Relationships

Although the COCOM estimating relationships (table 13) pertain to vehicle subsystems, whereas those for SSCOM pertain to vehicle programs, both models consist of terms which account for the same cost-dependent characteristics: cost coefficients, historical indices, aerospace hardware cost index, prior production, learning curves, production quantities.

Ground test equipment and nonrecurring facility costs are estimated for a basic launch rate of four vehicles per year. Subsequently, recurring cost estimates include additional funds for these facilities whenever the basic rate is exceeded. These additional funds then provide the increased capability at no further capital cost for the duration of the program.

Of particular interest is the cost of recycling the entry research vehicles since very little historical data on reuse of spacecraft exists. At the onset of the study, it was planned to estimate recycle costs by detailed pricing methods. This approach required detailed definition of refurbishment operations, maintenance functions, recycle schedules, manpower estimates, refurbishment hardware and special tools. Midway in the study, it became apparent that the use of the two different costing methods could be misleading, particularly when the refurbishment-to-new unit cost ratio is considered. A 2:1 cost model-to-pricing ratio would result in a 50 percent lower ratio of refurbishment-to-new unit cost if pricing techniques were applied to refurbishment and recycling. It was decided at this point to retain the COCOM costing method for refurbishment. COCOM determines cost of refurbishment by applying refurbishment-to-new unit ratios of each subsystem to the subsystem new unit cost. The critical parameter in this analysis is, then, the evalua-

TABLE 13

TYPICAL PRICING EQUATION

Cost item	Cost coefficients	Weight comparison	Adjustment for required quantity	Aerospace Price Index
$C_{item} =$	$\left(P_{rct}\right)\left(C_{ss}\right)$	$\left(\frac{W_{ss}}{W_{ref}}\right)^{W_{exp}}$	$\left[\left(\frac{N_{req} + N_{prior}}{N_{ref}}\right)^{L_{exp}} - \left(\frac{N_{prior}}{N_{ref}}\right)^{L_{exp}}\right]$	$\left(\frac{Y_{mp} - T_{ref}}{Y_{ref} - T_{ref}}\right)$

C_{item}	Cost item (e.g., structure--Flight Test Articles)
P_{rct}	Portion of subsystem cost applicable
C_{ss}	Cost of referenced (library) subsystem
W_{ss}	Weight of subsystem being priced
W_{ref}	Weight of referenced subsystem
W_{exp}	Weight relationship exponent
N_{req}	Number of these items required
N_{prior}	Number produced prior
N_{ref}	Number of reference items produced
L_{exp}	Learning curve exponent
Y_{mp}	Year of occurrence (midpoint year for development)
Y_{ref}	Year (midpoint) of referenced subsystem
T_{ref}	Time point for Aerospace Price Index

tion of ratio of refurbishment-to-new unit cost. This ratio was estimated by the following comparisons:

(1) Number of components refurbished versus number of components per subsystem.

(2) Weight of items refurbished or replaced versus weight of subsystem.

(3) Man-hours to evaluate subsystem after recovery of entry vehicle versus estimated man-hours to perform factory inspection and functional checks of new subsystem.

(4) Schedule span time to perform a subsystem refurbishment versus time to fabricate and install new subsystem.

(5) Schedule span time to conduct subsystem functional checks after refurbishment versus time to perform checks on new subsystem.

In addition to the above comparisons, the following criteria were established in estimating heat shield and recovery subsystem refurbishment cost ratios:

(1) The cost of heat shield refurbishment is equal to the installed cost of a new heat shield plus the cost of removing the expended one.

(2) The recovery system is refurbished by completely replacing the main canopy units and the emergency chutes.

Further confidence in subsystem refurbishment cost ratios was obtained by examination of X-15 subsystem refurbishment and maintenance costs relative to the new subsystem costs and comparing these values with the ratios estimated for this cost analysis where similarity of subsystems existed. The X-15 and HL-10 entry research vehicle refurbishment cost ratios are compared below:

Subsystem	X-15	HL-10
Reaction control	0.015	0.100
Electrical power	0.034	0.100
Instrumentation	0.014	0.015
Navigation and guidance	0.054	0.010
Structure	0.060	0.10

The X-15 data were derived from a refurbishment study* by extracting pure refurbishment costs. Reaction control figures are higher for the HL-10

*"Survey of Operation and Cost Experience of the X-15 Airplane as a Reusable Space Vehicle," J. E. Love and W. R. Young, NASA TN D-3732.

because of the much more severe heating on the thrustor units. The electrical power ratio is higher because of larger number of batteries in the HL-10. The guidance ratios are lower for the HL-10 which carries a large percentage of solid state units like computers which require no refurbishment, while the IMU (requiring periodic removal and calibration) is the major component in the X-15 guidance system. The structural refurbishment cost ratio of the HL-10 is 67 percent higher because of the additional hatches, seals, pressure shell complexities and its heat shield attachment fittings.

3. Inputs

In the COCOM analysis, 20 subsystems were identified, and weight was used as the cost dependent parameter. The design and schedule inputs included:

61 Hardware entries

146 Development schedule entries

133 Operational schedule entries

Nearly 700 significant historical program characteristics are required for estimates used in this study. These characteristics are changeable from one cost estimating task to another depending on the peculiarities of the system being evaluated. For example, a different class of subsystems (liquid propulsion versus solid propulsion) or a different stable of launch vehicles would necessitate a change in the historical program characteristics. Thus, a unique set of characteristics related to the particular HL-10 system design being estimated was used.

4. Outputs

COCOM output data are reported in two categories: nonrecurring (development) and recurring (operational). Nonrecurring costs include all charges except those incurred for research flights, including recovery expense.

Nonrecurring costs are provided to a detail level of 218 items, then recapped for fiscal funding. Recurring costs number 100 items per year, plus a summary at the end of the operational span. In addition, a cumulative total cost is reported for nonrecurring items and for the end of each operational year.

IV. VEHICLE SIZE SELECTION ANALYSIS

One of the major tasks performed in this study was the selection of one vehicle size for further in-depth design and study. The principal goal was to identify the vehicle size and crew complement that minimizes total program cost and maximizes the potential research value. In this evaluation, no maximum acceptable funding level was established; however, consideration was given to achieving a high research "value" per dollar of program cost. Likewise, the minimum acceptable potential research accomplishment was not a constraint in the analysis, but the selection rationale included the desirability of assigning each research task on at least one flight.

The specific measures of effectiveness established were as follows:

(1) Value of research accomplished

(2) Number of research tasks assigned

(3) Resource utilization--a small or negligible crew resource margin and a large weight resource margin being considered desirable.

In addition to these specific measures of effectiveness, orbital payload capability and several other factors were also considered.

The methodology used to obtain numerical values for the selected measures of effectiveness and cost estimates for the various crew and vehicle combinations was discussed in section II. It should be pointed out that these data, while principally used in selection of the vehicle, also can be used to assess the influence of vehicle size on research potential and project cost--another study objective.

A. CANDIDATE SYSTEMS

The five HL-10 designs considered as candidates in this analysis were vehicles sized for 1, 2, 4, 6, and 8 men. However, each of these vehicles was considered with either full crew complements or reduced complements or both. The specific designs selected are identified in table 14. Each design is denoted by a letter and a number indicating the vehicle size and crew size, respectively. The selection of these particular vehicle and crew combinations for detailed study was discussed in section IIC.

TABLE 14

CANDIDATE DESIGNS

Crew complement	Vehicle length 20.0 ft (6.10 m)	21.25 ft (6.48 m)	23.4 ft (7.13 m)	25.0 ft (7.62 m)	26.4 ft (8.05 m)
1-man crew	A/1	B/1			
2-man crew		B/2	C/2		
3-man crew			C/3	D/3	E/3
4-man crew				D/4	
5-man crew				D/5	E/5

The amount of crew and weight resources available for research in each of the candidate vehicles is summarized in table 15. It will be noted that the full amount of crew time available in each vehicle is not all available for performing research tasks. Some crew time is required to perform basic flying tasks independent of the research being performed. An allowance of 0.7 man second/second is made for these basic tasks, where the term man second/second is the unit of measure to show the fraction of one man's time, in seconds, expended on a given task in any second of mission time.

TABLE 15

CANDIDATE DESIGN RESOURCES

Designation		A/1	B/1	B/2	C/2	C/3	D/3	D/4	D/5	E/3	E/5
Weight	lb (kg)	170 (77)	645 (297)	135 (61)	1020 (463)	510 (231)	1075 (488)	811 (368)	525 (239)	1028 (466)	482 (219)
Crew	$\frac{\text{man-sec}}{\text{sec}}$	0.3	0.3	1.3	1.3	2.3	2.3	3.3	4.3	2.3	4.3

B. ANALYSIS RESULTS

As discussed previously, numerical values were developed for the three measures of effectiveness selected, and cost estimates were produced for each of the candidate vehicles. In addition to the candidate vehicle and crew combinations, various size flight plans were also considered, comprising 5, 7, 11, and 15 flights. Thus, a matrix of 40 programs was analyzed.

1. Value of Research Accomplished

The first measure of effectiveness selected is the "value of research accomplished" which is referred to as the program research potential. Data for the program research potential for each combination design and flight plan system were developed with the flight loading model. Potential value accrues from research experiment assignment on a defined program without exceeding the crew and weight resources available. The 40 programs evaluated ranged in value from 1095 to 2992.

These research potentials for each of the vehicles and flight plan combinations are presented graphically in figure 5. It is desirable to select the vehicle which performs the "most" research measured in terms of the value of research accomplished. When using figure 5 in the selection process, it should be observed that the ordinate is truncated and the vehicles are indicated on the abscissa in order of increasing length, crew size and cost, but not proportional to the cost.

Increasing the number of crewmen on board the B and C size vehicles produces a favorable increase in the research potential value. Conversely, for the D and E size vehicles, increasing the number of men in the crew above three-man complement decreases the potential value of research that can be accomplished. This relationship of decreasing crew producing increased value requires investigation of the validity of omitting the D/2 vehicle from the candidate list. A cursory heuristic analysis indicates the D/2 vehicle has potential research value equivalent to the C/2 system and cost equivalent to the D/3 system. The omission of this design from consideration is valid.

Although a minimum one-man vehicle was not included in this study, the relative potential value can be assessed by considering its similarity with the A/1 design.

2. Number of Research Tasks Assigned

A further criterion which influenced the selection of a vehicle for in-depth design was the number of research tasks assigned to the flight programs. Fifty-two tasks were identified for establishing the vehicle research potential. Forty system programs were evaluated. The number of tasks assigned at least once ranged between 23 and 49. The tasks that could not be assigned in each system program are identified in table 16.

The number of experiments assigned at least once during an 11-flight program is presented in figure 6. This figure also indicates the ineffectiveness of additional crew men in the larger size vehicles. The A/1 design research accomplishment includes assignment of only one-half the desirable tasks. This characteristic would apply also to a one-man minimum system.

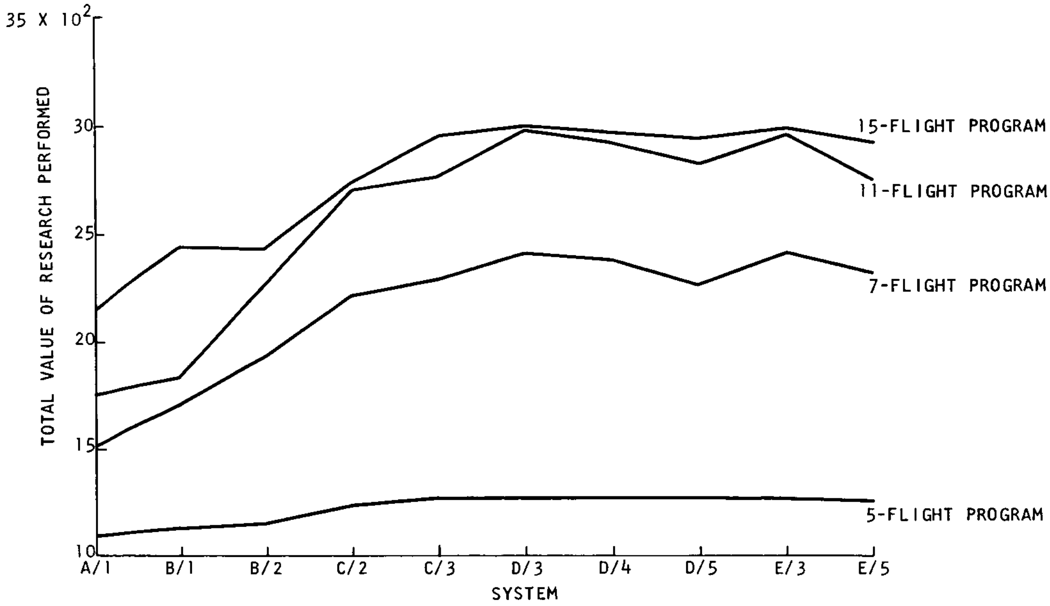

FIGURE 5. PROGRAM RESEARCH POTENTIAL

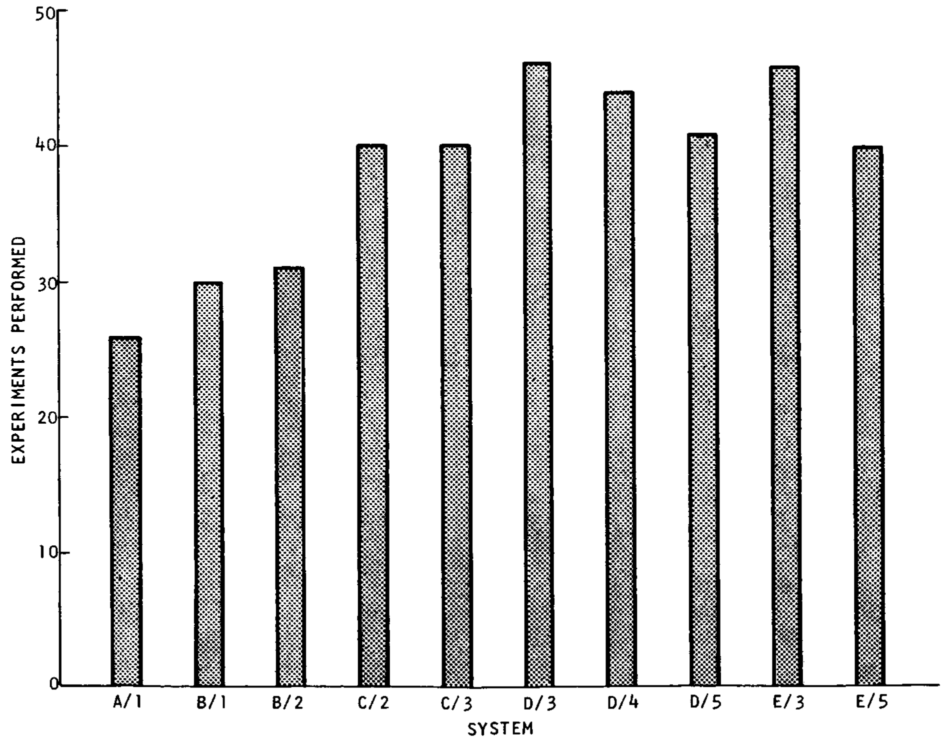

FIGURE 6. EXPERIMENT ASSIGNMENT FOR 11-FLIGHT PROGRAM

TABLE 16

RESEARCH TASK LOADING SUMMARY

No. flts	Veh size	Crew	Expt wt lb	Expt wt kg	Expt value	FM-3	FM-2	FM-5	GN-4	FM-4	GN-5	GN-1	FC-1	FM-17	GN-6	FM-6	GN-2	SM-9	FC-2	GN-3	FC-3	PP-3	PP-2	GN-7	SM-14	FC-4	SM-11	HF-1	FM-16	SM-15	FM-9	FM-18	FM-19	SM-18	SM-12	AV-2
					Excluded research tasks →																															
5	A	1	170	77	1095	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	
	B	1	645	297	1126	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X			X	X	X	X	X	
		2	135	61	1142	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	C	2	1020	463	1237	X		X	X	X	X		X	X	X	X	X		X	X	X	X	X			X		X			X	X	X	X	X	
		3	510	231	1268	X		X	X	X	X		X	X	X	X	X		X	X	X		X			X		X			X	X	X	X	X	
→	D	3	1075	488	1268	X		X	X	X	X		X	X	X	X	X		X	X	X		X			X		X			X	X	X	X	X	
		4	811	368	1268	X		X	X	X	X		X	X	X	X	X		X	X	X		X			X		X			X	X	X	X	X	
		5	528	239	1268	X		X	X	X	X		X	X	X	X	X		X	X	X		X			X		X			X	X	X	X	X	
	E	3	1028	467	1268	X		X	X	X	X		X	X	X	X	X		X	X	X		X			X		X			X	X	X	X	X	
		5	482	219	1259	X		X	X	X	X		X	X	X	X	X		X	X	X		X			X		X			X	X	X	X	X	
7	A	1	170	77	1506	X	X	X		X	X		X	X	X	X		X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X
	B	1	645	297	1702	X	X	X		X	X		X	X		X		X	X		X	X	X			X	X	X			X	X	X		X	X
		2	135	61	1920				X		X		X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	C	2	1020	463	2214						X		X	X		X		X	X		X	X	X			X	X	X			X	X	X		X	
		3	510	231	2285						X			X		X		X				X		X		X	X	X		X	X	X	X	X	X	
→	D	3	1075	488	2416						X			X		X										X		X			X	X	X		X	
		4	811	368	2381						X			X		X										X		X	X	X	X	X	X		X	
		5	528	239	2264						X			X		X		X				X		X		X	X	X	X	X	X	X	X	X	X	
	E	3	1028	467	2416						X			X		X										X		X			X	X	X		X	
		5	482	219	2324						X			X		X		X				X		X		X	X	X		X	X	X	X	X	X	
11	A	1	170	77	1756	X	X	X	X	X	X	X			X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	
	B	1	645	297	1833	X	X	X	X	X	X	X			X	X	X	X		X	X	X	X			X	X	X		X	X	X	X			
		2	135	61	2277				X		X		X		X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	C	2	1020	463	2717						X		X			X		X					X			X	X	X		X	X	X	X			
		3	510	231	2758										X	X		X				X				X	X	X		X	X	X	X	X		
→	D	3	1075	488	2972																					X		X		X	X		X	X		
		4	811	368	2916											X						X				X		X			X	X	X	X		
		5	528	239	2822											X		X				X				X	X	X		X	X	X	X	X		
	E	3	1028	467	2966																					X		X		X	X	X	X			
		5	482	219	2758										X	X		X				X				X	X	X		X	X	X	X	X		
15	A	1	170	77	2135	X	X				X	X			X	X				X	X	X	X	X		X		X	X	X	X	X		X	X	
	B	1	645	297	2440	X	X				X	X				X					X	X	X					X		X	X	X			X	
		2	135	61	2426				X		X		X		X	X				X	X	X		X	X	X		X	X	X	X	X		X	X	
	C	2	1020	463	2732						X		X			X					X					X		X		X	X				X	
		3	510	231	2941											X										X		X		X	X			X		
→	D	3	1075	488	2992																							X		X	X					
		4	811	368	2966																					X		X		X	X					
		5	528	239	2941											X										X		X		X	X			X		
	E	3	1028	467	2992																							X		X	X					
		5	482	219	2921										X	X										X		X	X	X	X			X		

3. Resource Utilization

In selecting the candidate system for in-depth design, utilization of available resources was a significant factor considered. It is important to have some weight resource margin for future growth, and it is desirable to minimize the amount of unused crew time resource. For example, if the analysis showed that one crew member was never used, it is obvious that the flight should be flown without this man.

Crew and weight resources unused in performing the defined research (in the optimum manner within established constraints) are presented in table 17 for all the candidate systems flown in the 11-flight program. The entry condition sequence for this program was A, B, C, C, F, F, F, G, G, G and I. The average values for the unused resources are shown in figure 7. In general, these data show that, for the minimum systems (A/1, B/1, C/2, etc.), the system is crew constrained. This means that no further tasks could be assigned because crew resource was required. As shown in table 17, there are many flights without any unused crew resource. These data also show that, if the crew complement is increased, the vehicle becomes weight constrained.

TABLE 17

UNUSED RESOURCES FOR 11-FLIGHT PROGRAM

Sequence of flights			1	2	3	4	5	6	7	8	9	10	11	Av
	Veh size	No. of crew												
Weight, kg	A	1	54.4	22.7	20.4	24.9	9.1	27.2	49.9	52.2	43.1	45.4	40.8	37.6
	B	1	296.6	54.4	217.7	199.6	183.7	195.0	224.5	240.4	235.9	97.5	124.7	187.8
		2	61.2	22.7	4.5	9.1	9.1	4.5	34.0	47.6	43.1	29.5	24.9	26.3
	C	2	462.7	424.1	387.8	369.7	285.8	265.4	292.6	410.5	99.8	70.3	172.4	294.8
		3	231.3	176.9	179.2	156.5	725.7	52.2	34.0	179.2	61.2	31.8	163.3	125.6
	D	3	487.6	453.1	351.5	333.4	249.5	115.7	95.3	367.4	131.5	95.3	242.7	250.4
		4	367.9	313.4	231.8	213.6	107.0	109.3	54.9	279.4	66.2	98.0	281.7	192.8
		5	239.5	194.1	164.7	142.0	58.1	42.2	24.0	187.3	35.4	1.4	153.3	112.9
	E	3	466.3	426.4	328.9	310.7	226.8	93.0	72.6	344.7	63.5	27.2	174.6	230.4
		5	218.6	173.3	143.8	121.1	37.2	29.0	3.2	166.5	170.1	19.1	132.4	110.2
Weight, lb	A	1	120	50	45	55	20	60	110	115	95	100	90	83
	B	1	645	120	480	440	405	430	495	530	520	215	275	414
		2	135	50	10	20	20	10	75	105	95	65	55	58
	C	2	1020	935	855	815	630	585	645	905	220	155	380	650
		3	510	390	395	345	160	115	75	395	135	70	360	277
	D	3	1075	990	775	735	550	255	210	810	290	210	535	552
		4	810	691	511	471	236	241	121	616	146	216	621	425
		5	528	428	363	313	128	93	53	413	78	3	338	249
	E	3	1025	940	725	685	500	205	160	760	140	60	385	508
		5	482	382	317	267	82	64	7	367	375	42	292	243
Crew, man-sec/sec	A	1	--	--	0	0	0	0	0.2	0.2	0.2	0.1	0.2	0.1
	B	1	--	--	0	0	0	0	0.2	0.2	0.2	0.1	0.1	0.1
		2	--	--	0.1	0.1	0.1	0.1	0.3	0.8	0.8	0.7	0.7	0.4
	C	2	--	--	0.5	0.3	0	0.3	0.3	0.5	0.4	0.2	0.2	0.3
		3	--	--	1.3	1.1	0.8	1.0	0.5	1.2	1.0	0.7	1.3	1.0
	D	3	--	--	1.1	1.4	0.6	0.4	0	0.8	0.3	0	0	0.5
		4	--	--	2.1	1.9	1.6	1.8	0.5	1.4	1.0	0.3	2.3	1.4
		5	--	--	3.3	3.1	2.8	3.0	2.5	3.2	3.0	2.5	2.3	2.9
	E	3	--	--	1.1	1.4	0.6	0.4	0	0.8	0.8	0.1	0.9	0.7
		5	--	--	3.3	3.1	2.8	3.0	2.5	3.2	3.0	2.5	3.3	3.0

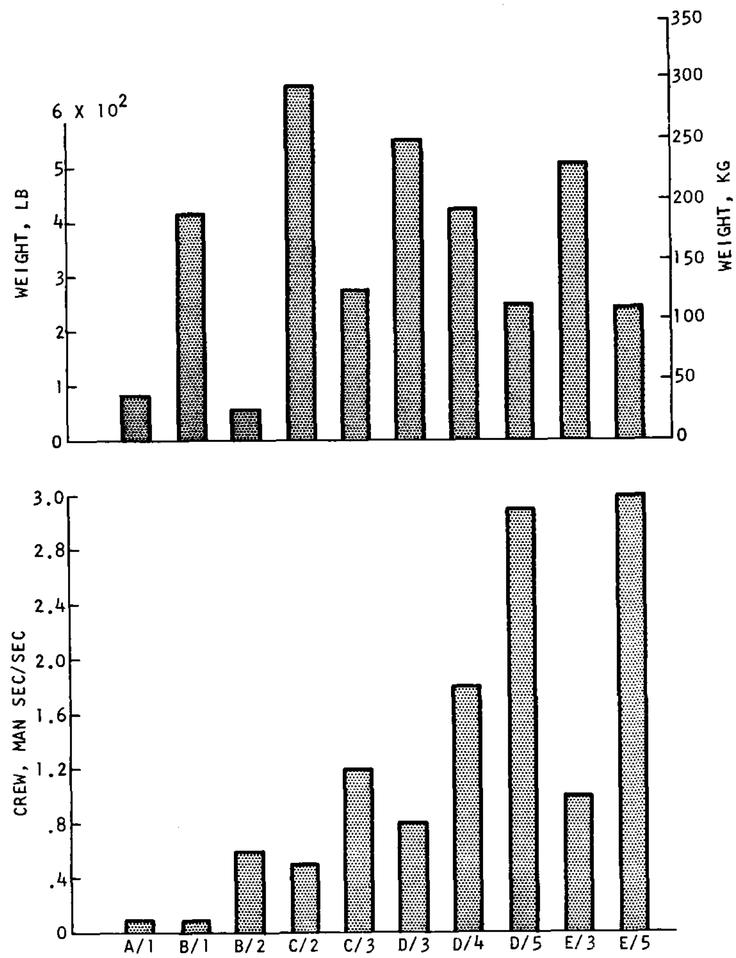

FIGURE 7. UNUSED RESOURCES IN 11-FLIGHT PROGRAM

In considering the data of figure 7, it is important to consider that of figures 5 and 6. As an example, consider the C/2 system. Figure 7 shows that this system apparently has the greatest capacity for growth and makes efficient use of the crewmen. However, figures 5 and 6 show that the value of research performed and the number of research tasks accomplished are lower than the D/3 vehicle which also has efficient crew utilization and good growth capability. Therefore, figures 5, 6 and 7 clearly indicate the superiority of the D/3 system.

4. Program Costs

The program costs were estimated, using the Space System Cost Model (SSCOM), for the 10 candidate vehicle and crew combinations, each with four potential flight research programs. These cost estimates are tabulated in table 18 and depicted graphically in figure 8. Various pertinent milestones of any potential research program are indicated on the abscissa in this figure. This affords an opportunity to visualize the relative incremental cost of additional flights on any defined program. The verification flight milestone includes two unmanned verification missions. Data for the smallest crew complement considered for each candidate vehicle size have been identified. Each additional crew member included in the complement increases the program cost about 1.5 percent.

TABLE 18

PROGRAM COSTS

System	Nonrecurring costs, dollars	Total program costs, dollars			
		5 Flt	7 Flt	11 Flt	15 Flt
A/1	616 x 10^6	737 x 10^6	794 x 10^6	888 x 10^6	979 x 10^6
B/1	647	776	835	930	1022
B/2	666	797	857	954	1047
C/2	725	863	925	1024	1120
C/3	743	882	945	1046	1143
D/3	794	939	1004	1107	1206
D/4	808	954	1020	1124	1223
D/5	811	958	1024	1128	1228
E/3	846	996	1063	1169	1270
E/5	872	1025	1093	1200	1303

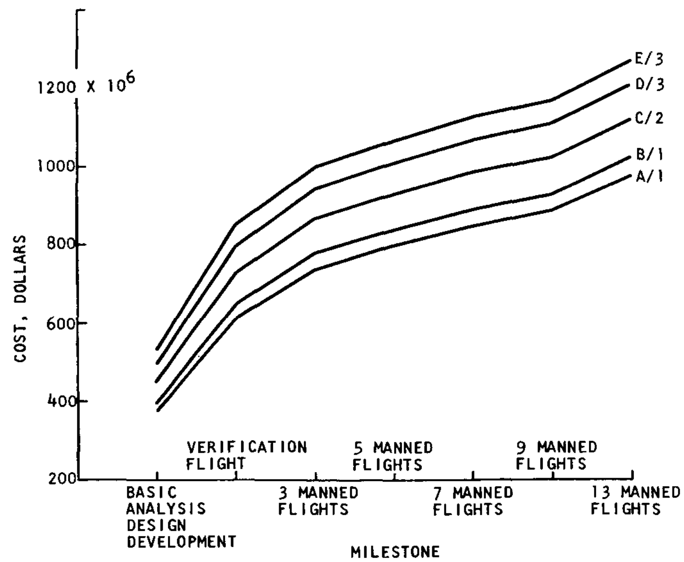

FIGURE 8. COSTS OF POTENTIAL FLIGHT RESEARCH PROGRAMS

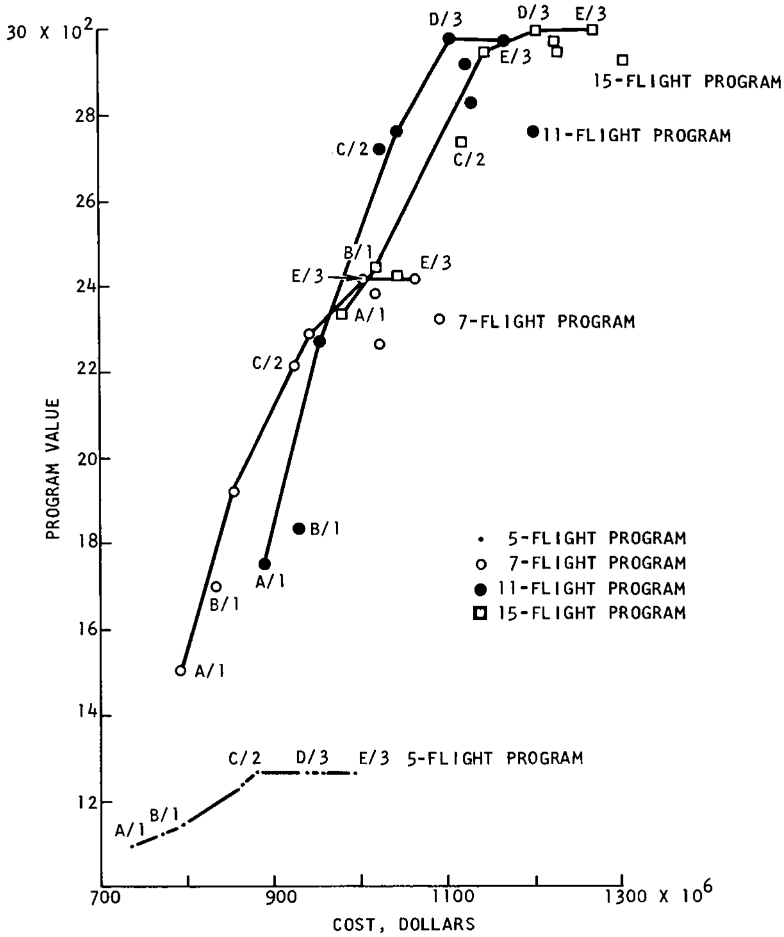

FIGURE 9. PROGRAM VALUE AS A FUNCTION OF COST

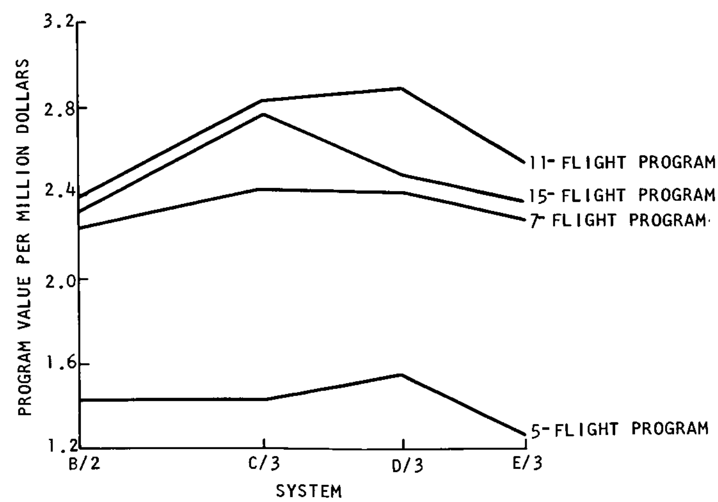

FIGURE 10. POTENTIAL RESEARCH VALUE ACHIEVED PER MILLION DOLLARS INVESTED

6. Orbital Payload Capability

A secondary consideration in the selection of a manned entry research vehicle design is its adaptability to orbital objectives. A measure of this adaptability is the cost per pound of orbital payload (fig. 11).

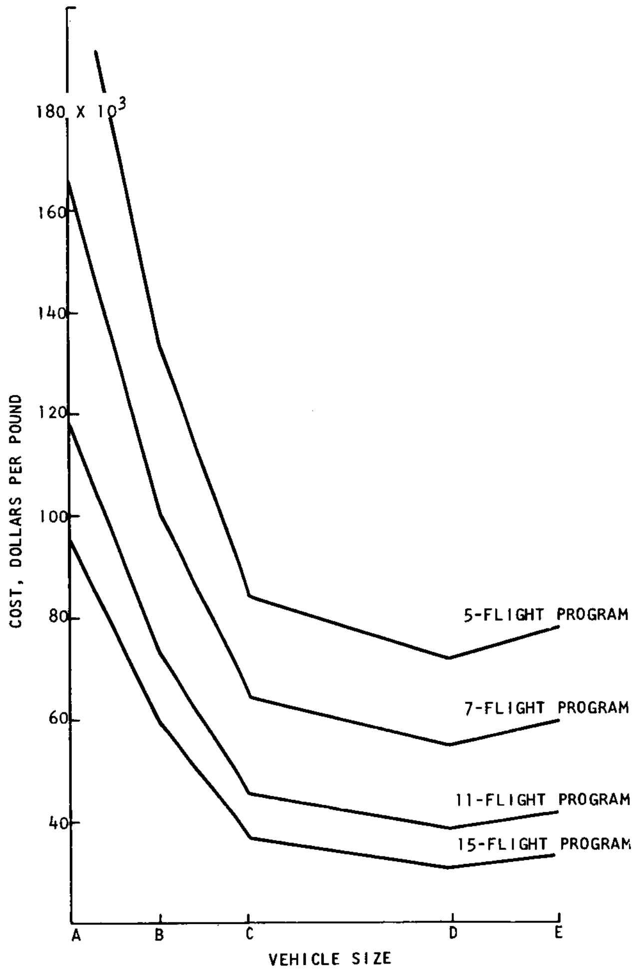

FIGURE 11. ORBITAL PAYLOAD COSTS

C. SELECTION RATIONALE

The selection criteria included two principal qualities: minimum program cost and maximum potential research value. These two criteria are not always compatible; increasing value generally requires additional resources or increasing cost. In this study, the D/3 vehicle was found to have the maximum potential research value, but four other systems incurred higher cost. These other systems could therefore be excluded from further consideration.

The systems with less potential research value than D/3 can be obtained at a reduced cost, and comparison produces a conflict between the principal criteria. Additional criteria were introduced including: achieving a high value per dollar (fig. 10), assigning most of the research tasks (fig. 6), optimizing the residual resources (fig. 7), and minimizing the cost of each unit of weight available for experimental equipment in orbit (fig. 11). The candidate systems are ranked in accordance with these criteria in table 20. On each of these criteria, the D/3 vehicle ranked ahead of other systems.

The evaluation in accordance with these basic criteria indicates a preference for the D/3 vehicle. Additional factors which were difficult to reflect quantitatively in the basic criteria are discussed in the next section.

D. OTHER CONSIDERATIONS

In addition to the five quantitative criteria applied in the preceding section, the following qualitative factors were considered.

(1) Visibility. Forward and side visibility of ground during final flare, touchdown, and initial slideout must meet NASA and Air Force research pilots' criteria for adequacy. In particular, the A and B size vehicles do not offer acceptable visibility (see Part IV).

(2) Packing density. Use of the allowable 55 psf (270 kg/m^2) wing loading allows research equipment weight to reach a value such that the packing density becomes unrealisticly high on the A and B size entry vehicles. In other words, the volumes available for experiments constrain weight available for research on the A and B sizes.

(3) Maximum entry velocity with Saturn IB. Attainable entry velocity increases as the vehicle size is reduced. Highly elliptical orbits can achieve 31 500 fps (9.4 km/sec) to 34 000 fps (10.4 km/sec) velocity depending on entry vehicle size.

(4) Impact of modifying entry vehicle with crew transfer tunnel. An aft tunnel in the entry vehicle for crew and return equipment transfer is desirable if the entry vehicle is to perform rendezvous, docking, and transfer experiments. A minimum tunnel will fit in the D and E size vehicles without altering important aerodynamic outer lines.

(5) Mission applications. Based on both NASA and USAF studies, logistics mission applications require a crew capacity of at least 3 men with some requirements as high as 12. An entry research vehicle too small to be considered a logistics mission prototype would represent a dead-end investment after all research was accomplished.

(6) Landing engine. Go-around capability is a desirable feature in any horizontal landing vehicle. Turbojet engines, pulse-jets, subsonic air turborockets, and conventional rocket engines were con-

TABLE 20

SYSTEM SUMMARY

	Cost (increasing)	Value (decreasing)	Residual resource		Value/dollar (decreasing)	Task assignment (decreasing)	Orbital payload capability (decreasing)
			Crew (increasing)	Weight (decreasing)			
A/1	1	10	1	9	8	10	10
B/1	2	9	2	5	6	8	8
B/2	3	8	4	10	5	9	9
C/2	4	7	3	1	4	7	6
C/3	5	6	7	6	2	5	7
D/3	6	1	5	2	1	1	1
D/4	7	3	8	4	3	3	2
D/5	8	4	9	7	7	4	3
E/3	9	2	6	3	9	2	4
E/5	10	5	10	8	10	6	5

sidered; all were found to be extremely expensive in terms of entry vehicle weight and complexity. Nevertheless, the possible payoff in mission success makes a landing engine experiment on an orbital vehicle a worthwhile subject for this flight research program. A turbojet engine (J-97) has been selected because it is a proven design and can be installed in an entry vehicle for research purposes. However, because of its size, this engine can be installed only in the C, D and E vehicles.

(7) Vehicle abort. Because of weight and space limitations, crew escape must be via ejection seat for the A and B vehicles. Larger sizes use a large parachute to recover the vehicle. This emergency recovery technique is preferred since normal abort modes involve water landing where the entry vehicle is specifically designed to support crew survival.

The selected D/3 vehicle is tested by the above considerations with the following conclusions drawn:

(1) The D/3 vehicle is satisfactory for visibility.

(2) The D/3 vehicle does not pose any packing density problems.

(3) The D/3 vehicle can achieve an entry velocity of 32 600 fps (9.9 km/sec) by the use of a highly elliptical orbit. If near-Earth orbits are used, the entry velocity reduces to 28 900 fps (8.8 km/sec). These velocities are only marginally acceptable for supercircular entry research because of the low radiative heating encountered. It should be noted that even the smallest A size vehicle is only capable of being entered at a velocity of 34 000 fps (10.4 km/sec) using Saturn IB and a highly elliptical orbit.

(4) An adequate crew transfer tunnel can be installed in the D/3 vehicle without serious structural change and alteration of the aerodynamic lines.

(5) If the requirement for an operational logistics mission vehicle is six men, it can be met with the D size.

(6) A J-97 turbojet engine can be installed in the D/3 vehicle.

(7) The D/3 vehicle permits the use of large parachutes for vehicle emergency recovery from an aborted mission.

A summary of the qualitative considerations examined are given in table 21 for the five entry vehicle sizes. From this table and the preceding discussion, the general conclusion can be drawn that the D/3 vehicle, as selected by the quantitative criteria, remains the best choice after being tested by the seven qualitative considerations.

The D/3 entry vehicle is therefore selected for in-depth design and costing. A design description is found in Part VII of this report.

TABLE 21

SUMMARY OF CONSIDERATIONS

Vehicle size	Visibility	Packing density	Maximum velocity* Saturn 1-B, fps (km/s)	Aft tunnel installation	Mission application	Landing engine	Vehicle abort
A	U	M	34 000 (10.4)	U	U	U	M
B	U	M	33 300 (10.2)	U	U	U	M
C			32 600 (9.9)	U	M		
D			32 300 (9.8)				
E			31 500 (9.6)				

* Highly elliptical orbits   U = unsatisfactory   M = marginal

V. RESEARCH PROGRAM DEFINITION

The D/3 configuration was selected as the best vehicle and crew combination for a more detailed study which is reported in Part VII. The only significant difference in the selected vehicle characteristics that influence the research program definition is a reduction in weight available for research equipment from 1075 pounds (487 kg) to 1030 pounds (466 kg). The other characteristics do not alter the cost estimate for the D/3 design. All discussion in this section, therefore, is predicated on use of this configuration.

Basic parameters considered in selecting the recommended flight plan were the value of research information obtained, the number of experiments to be loaded, the number of flights in the program, cost, and utilization of available equipment weight and crew capability for research.

A. INFLUENCE OF NUMBER OF FLIGHTS

The information value of the research program is related to cost with number of flights as a parameter in figure 12. The value/cost ratio is related to the number of flights in the program in figure 13 which indicates that the 11-flight program yields the maximum value relative to cost.

Experiment loading as a function of number of flights is shown in figure 14. The number of experiments, of the 52 considered, which would be loaded and not loaded is indicated for each flight program. The maximum loading for any flight program considered is 50 experiments, which occurs in the 11- and 15-flight programs. It will be noted that this number does not agree with that quoted earlier for the D/3 vehicle in an 11-flight program. This occurs because the D/3 vehicle design in the flight loading model was more highly refined in this phase than in the preliminary vehicle size selection phase.

Figures 15 and 16 depict average utilization of the available experiment weight and crew capability as a function of the number of flights in the program. Also shown are the residual, or unused, experiment weight and crew capability. The crew utilization numbers include performance of normal flight tasks as well as research tasks. Figures 15 and 16 indicate that the 5-, 9-, and 11-flight programs yield the largest average loaded experiment weight, while the 11-flight program maximizes average use of crew capability.

The selected flight plan is the 11-flight program. This selection is based on the data for 5-, 7-, 9-, 11-, 15-flight programs portrayed in figures 12 to 16. The 11-flight program yields the maximum value/cost ratio, and loads the maximum number of experiments (50) with the highest information value (2954) of any flight program studied, with the exception of the 15-flight program. The 15-flight program also loads 50 experiments, with an information value of 2992. This increase in value is insignificant when compared to the increase in cost over the 11-flight program (fig. 12). Crew utilization for research is also maximized by the 11-flight program, while utilization of available equipment weight for research is one of the most efficient for the flight programs studied.

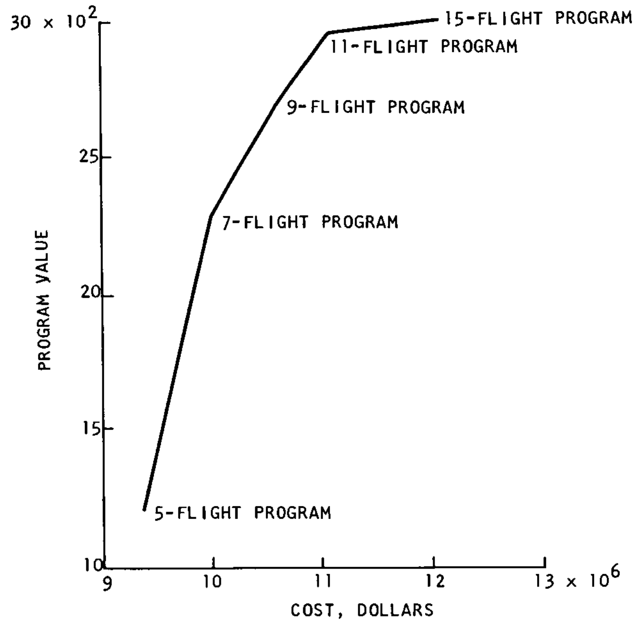

FIGURE 12. VALUE OF RESEARCH PROGRAM AS RELATED TO COST

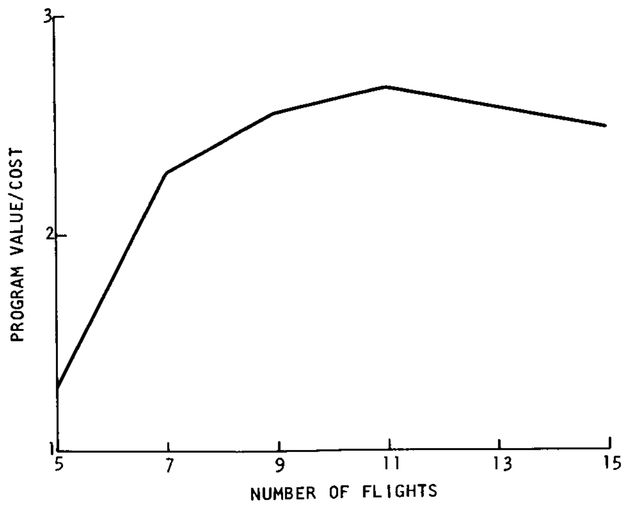

FIGURE 13. VALUE/COST RATIO AS RELATED TO NUMBER OF FLIGHTS

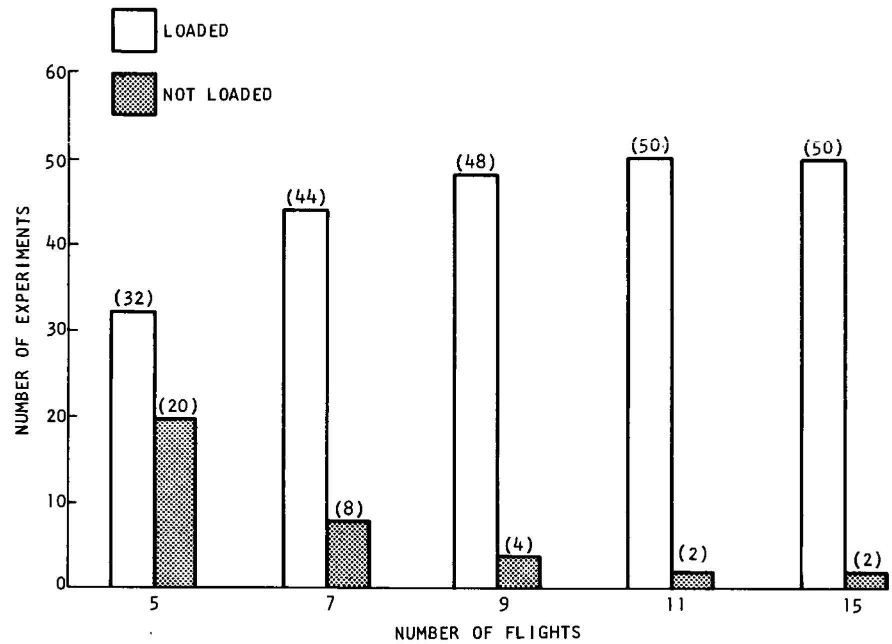

FIGURE 14. EXPERIMENT LOADING AS RELATED TO NUMBER OF FLIGHTS

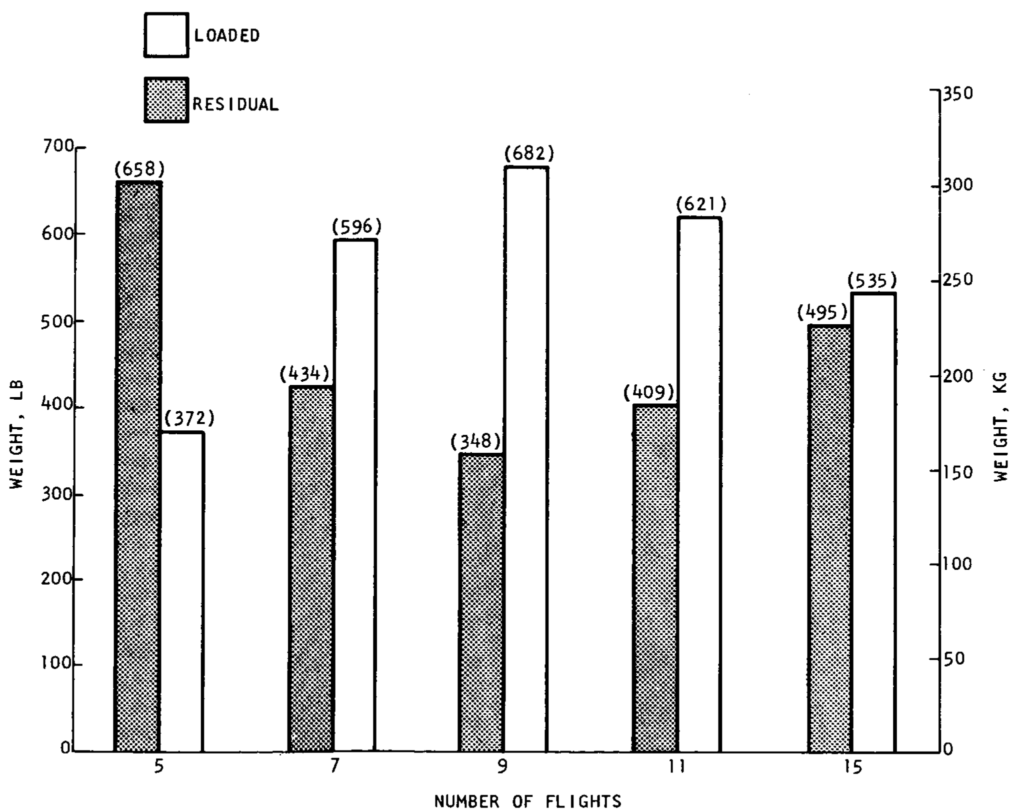

FIGURE 15. EXPERIMENT WEIGHT UTILIZATION

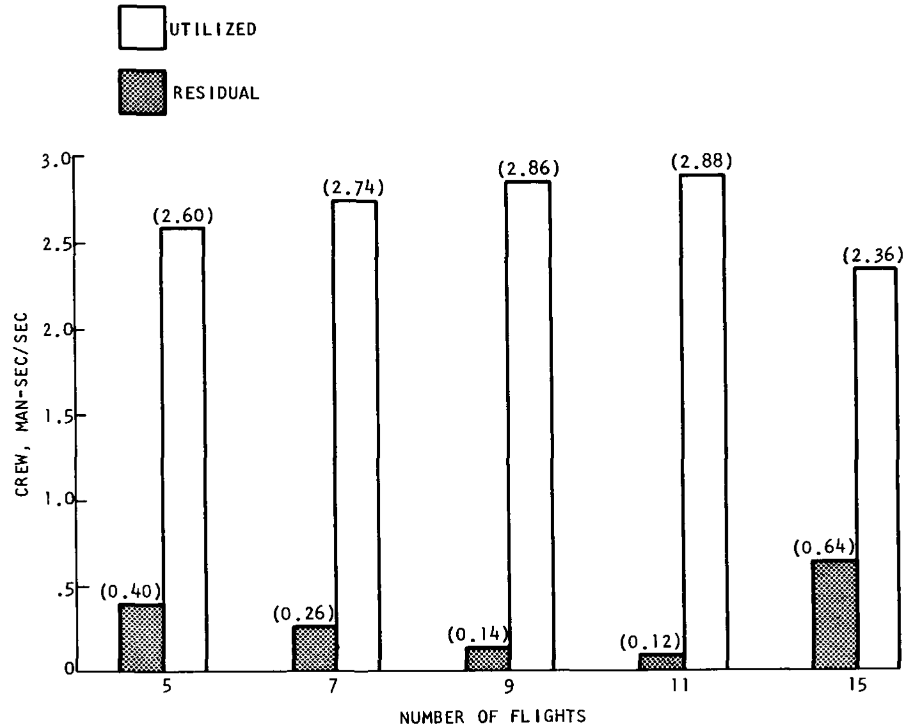

FIGURE 16. CREW UTILIZATION

B. VARYING ENTRY FLIGHT PATTERN

The pattern, or type of flights, within the programs considered in the previous section were established by inspection, with judgment as to the sequence which would yield the highest number of experiments loaded and the highest information value, within the constraints. An analysis was performed on the 11-flight program for the purpose of defining those experiments which were not loaded to full value and to determine if, within certain ground rules, the sequence of flights could be modified such as to yield more total value. The ground rules were:

(1) No additional flights added

(2) No experiment to be deleted from the flight program

(3) Unmanned flights (A and B) to be maintained.

This analysis identified 23 experiments, as shown in table 22, which were not loaded to their full information value. Of these, 13 had the potential to be improved by rearranging the sequence of the flight program. The remainder required additional flights for potential improvement. An analysis of the 13 experiments showed the following potential improvement by type of flight added. (Note: There are no D or H flights in the 11-flight program under consideration.)

Type of flight added	No. of experiments potentially improved
C	10
F	9
D	5
I	2
G	1
H	1

Since the analysis also indicated that no experiments would be deleted from the program if a G type flight were exchanged for another type, the most judicious rearrangement appeared to be the exchange of a G flight for an additional C flight. This optional 11-flight sequence was evaluated with the flight loading model, and yielded higher total experiment value than the original sequence. In the optional sequence, seven experiments were improved in information value, five of which were fully loaded (table 22). Two experiments were decreased in value, but no experiments were deleted from the flight program. There was no change in value for the remaining experiments.

An analysis was performed on the optional 11-flight program, as on the original program, to define experiments with potential for improvement by rearranging the sequence of the flight program, within the previously stated ground rules. There are seven such experiments. The potential for improvement by type of flight added is:

Type of flight added	No. of experiments potentially improved
G	2
I	2
D	2
H	1
C	1
F	0

TABLE 22

EFFECTS OF VARYING FLIGHT TYPE PATTERN FOR 11-FLIGHT PROGRAM

Experiments not loaded to full value	Original flight sequence (A B C C F F F G G G I)	Optional flight sequence (A B C C C F F F G G I)	Value improved		No change	Value decreased
			Fully loaded	Value increased		
FM-8	X		X			
FM-3	X	X				X
FM-2	X		X			
FM-7	X		X			
FM-13	X		X			
EV-2	X	X			X	
GN-1	X	X			X	
FC-1	X	X			X	
FM-17	X	X			X	
SM-8	X	X			X	
FM-14	X		X			
FM-6	X	X		X		
GN-2	X	X			X	
SM-3	X	X			X	
SM-9	X	X			X	
FC-2	X	X			X	
HF-2	X	X			X	
FC-4	X	X		X		
SM-10	X	X			X	
SM-12	X	X			X	
HF-1	X	X			X	
FM-16	X	X			X	
SM-15	X	X			X	
GN-5		X				X
Number of experiments for potential improvement by adding flights	23	19				
Number of experiments for potential improvement by changing sequence for 11-flight program (without deleting an experiment)	13	7				
Number of experiments increased in value in going from original to optional flight sequence	--	7				

The analysis also showed that exchange of a G or an I flight for another type would lead to complete deletion of experiments from the flight program. Also, since there are no D or H flights in the sequence, the only type flights which can be exchanged are C or F. Changing a C or F to a G leads back to the original flight sequence considered. Changing an F to a C has the potential for improving the value of one experiment. Changing either C or F to an I, D, or H has the potential for improvement as shown in the preceding listing.

The experiments improved by substitution of D, I, and H entry conditions are low in value, whereas the experiments improved by substitution of a G entry condition are high in value. However, the G substitution decreased the total potential research value. Therefore, the D, I, and H substitutions were not evaluated with the flight loading model. The optional 11-flight program sequence was judged to be optimum.

C. SELECTED FLIGHT PLAN

Table 23 compares the cost, value, number of experiments loaded, and weight and crew resource margins for the two 11-flight programs previously discussed. The cost and number of experiments loaded are identical for the two programs. The information value of the optional program is 52 points higher than the value of the original 11-flight program. Average weight resource margin, or unused experiment weight capability, is decreased to 376 pounds (171 kg) on the optional program. Average crew resource margin is increased slightly to 0.14 man second/second.

The selected flight plan is, therefore, the 11-flight program with the optional sequence (A, B, 3C, 3F, 2G, I). The experiment loading is shown in table 24. The only experiments not loaded are FM-9 and FM-19. These experiments require J-K and S flights, respectively. Since FM-9 was a secondary objective, it was not considered in the loading program. It was shown in the two 11-flight programs considered, that 50 experiments could be loaded with two C or G type flights included in the plan. Therefore, the option exists to load 51 experiments, including FM-19, by substituting an S for a C flight in the selected program. This would accomplish loading all 51 of the primary objective experiments, but would yield a lower total information value than the selected program.

There was no consideration given to reducing the crew complement below three to permit higher density loading of experiments. This was due to the fact that in each instance where an experiment was not loaded on an applicable flight, the reason was either a limitation in crew capability or constraints imposed by incompatibility with higher value experiments loaded on that flight. In no instance was weight availability a problem.

Crew constraints for all experiment loading programs studied were based on crew utilization ratios for the flight phase which, by comparison with other flight phases, appeared to require the maximum crew participation in research

TABLE 23

COMPARISON OF ORIGINAL AND OPTIONAL 11-FLIGHT PROGRAMS

		Original (A B C C F F F G G G I)		Optional (A B C C C F F F G G I)	
Cost (millions of dollars)		1107		1107	
Value		2954		3006	
Experiments loaded		50		50	
Resource margins					
Weight	Flight	lb	kg	lb	kg
	1	1030	466	1030	466
	2	860	390	860	390
	3	695	315	695	315
	4	680	308	680	308
	5	430	195	430	195
	6	310	141	505	229
	7	235	107	85	39
	8	325	147	45	20
	9	225	102	215	98
	10	425	193	700	318
	11	355	161	230	104
Crew (man sec/sec)					
	3	.2		.2	
	4	.2		.2	
	5	.1		.1	
	6	0		.2	
	7	0		0	
	8	0		.2	
	9	.1		.1	
	10	0		.2	
	11	.5		.1	
Average weight		409	186	376	171
Average crew		.12		.14	

TABLE 24

SELECTED FLIGHT PLAN EXPERIMENT LOADING

Experiment	Flight type/number loaded										
	A	B	C	C	C	F	F	F	G	G	I
	1	2	3	4	5	6	7	8	9	10	11
SM-1		X	X								
FM-8		X	X	X	X	X	X	X			
FM-3			X	X	X	X	X		X	X	X
FM-2			X	X	X	X	X	X			
FM-7		X	X	X	X	X	X	X			
FM-5						X	X	X			
GN-4					X			X	X	X	
FM-4						X	X		X		X
GN-5					X			X		X	
FM-13			X	X	X	X	X	X			
EV-2					X		X		X		X
SM-6		X	X	X							
GN-1			X	X		X			X		
FC-1			X	X	X	X	X	X			X
SM-2			X	X							
FM-17			X	X							X
SM-8					X		X		X		X
GN-6					X			X	X	X	
FM-14			X	X	X	X	X	X			
SM-7		X									
FM-6						X	X	X			
FM-12			X	X	X						
GN-2				X		X					
SM-5		X	X	X							
SM-17		X	X	X							
SM-3			X	X	X	X	X	X	X		X
SM-9			X	X	X	X	X		X		
FC-2									X	X	
GN-3					X			X	X	X	
FC-3							X	X			X
FM-15		X	X	X							
PP-3									X		X
PP-2							X				X
GN-7				X	X	X	X	X			X
SM-14		X	X								
HF-2			X	X	X	X	X	X	X		X
FC-4							X	X			
SM-10				X	X	X	X	X		X	
SM-12										X	
SM-13		X	X	X	X	X					X
PP-1	X	X									
SM-16			X	X							
AV-2		X									
SM-11			X	X	X						
HF-1									X		
FM-16			X	X	X	X	X	X			
SM-15										X	
FM-9 (not loaded)											
FM-18											X
AV-1		X	X	X							
FM-19 (not loaded)											
SM-18											X

tasks. This concession was made to minimize LP-90 computer time. The chosen flight phase for study is the period between pullout and 200 000-foot (60.9 km) altitude. To determine if there were other flight phases where crew constraints might be exceeded due to the selected experiment loading, an analysis was performed by flight phase and flight number. The results are shown in table 25 for both the selected (optional) 11-flight plan and the original 11-flight plan. The numbers in the chart include allocated crew utilization for normal flight tasks.

There are two cases in the selected flight plan where the maximum crew capability is exceeded, while there is one case with the original flight plan. These overloads can be resolved by selective deletion of experiments while observing the ground rule that no experiment be completely deleted from the flight program. The experiments for potential unloading are GN-6 on flight 6 for the original flight program, and FM-2, -13, -14 on flight 8, and GN-6 on flight 9 for the selected flight program. These deletions yield the minimum decrease in total program information value. The reduced values would be 2938 and 2972, respectively, for the original and the selected flight programs. This adjustment would not invalidate the selection of the optional 11-flight program as the recommended program.

TABLE 25

CREW RESEARCH TASK LOADING FOR 11-FLIGHT PROGRAM

Original flight plan (A, B, 2C, 3F, 3G, I):
first value noted
Selected flight plan (A, B, 3C, 3F, 2G, I):
value in parentheses
Crew utilization ratio X, (X) $\leq$ 3.0

Flight Phases									
Ascent (0 - 0.48 ksec)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)
1st orbit (0.48 - 5.9 ksec)	0.5 (0.5)	0.5 (0.5)	0.9 (0.9)	0.9 (0.5)	0.5 (0.5)	0.9 (0.9)	0.5 (0.8)	0.9 (0.9)	1.5 (1.5)
2nd orbit (5.9 - 10.3 ksec)	0.6 (0.6)	0.6 (0.6)	0.9 (0.9)	0.9 (0.6)	0.7 (0.6)	1.0 (1.0)	1.7 (2.0)	1.0 (1.0)	1.6 (1.6)
3rd orbit (10.3 - 13.7 ksec)	0.4 (0.4)	0.4 (0.4)	0.8 (0.8)	1.0 (0.6)	0.7 (0.7)	0.8 (1.1)	0.4 (0.7)	0.8 (0.8)	0.4 (0.4)
Deorbit and exoatmospheres (13.7 - 15.4 ksec)	0.7 (0.7)	0.7 (0.7)	0.9 (0.9)	1.0 (0.8)	0.9 (0.8)	1.1 (1.0)	1.3 (1.5)	1.1 (1.0)	0.7 (0.8)
400 000 to 280 000 ft (121.9 - 85.3 km) (15.4 - 15.6 ksec)	1.3 (1.3)	1.8 (1.8)	2.6 (2.6)	2.6 (2.0)	2.0 (2.0)	2.0 (2.5)	2.0 (2.1)	1.9 (1.9)	1.3 (1.0)
280 000 ft (85.3 km) to pullout (15.6 - 15.7 ksec)	1.5 (1.5)	2.0 (2.0)	2.8 (2.8)	2.7 (2.2)	2.3 (2.7)	3.0 (2.7)	2.3 (2.4)	2.9 (2.9)	1.9 (2.0)
Pullout to 200 000 ft (60.9 km) (15.7 - 16.7 ksec)	2.3 (2.3)	2.8 (2.8)	2.9 (2.9)	3.0 (2.8)	3.0 (3.0)	3.0 (2.8)	2.9 (2.9)	3.0 (2.8)	2.5 (2.9)
200 000 ft (60.9 km) to M = 6 (16.7 - 16.9 ksec)	1.7 (1.7)	2.2 (2.2)	2.7 (2.7)	3.5[a] (2.2)	2.4 (2.6)	3.0 (3.4)[b]	2.0 (2.8)	3.0 (2.7)	1.4 (1.7)
M = 6 to M = 2 (16.9 - 17.1 ksec)	1.0 (1.0)	1.0 (1.0)	1.1 (1.1)	1.8 (1.0)	1.1 (1.1)	1.6 (1.9)	1.6 (2.4)	1.6 (1.6)	0.8 (0.8)
M = 2 to M = 0.8 (17.1 - 17.2 ksec)	1.0 (1.0)	1.0 (1.0)	1.1 (1.1)	1.8 (1.0)	1.0 (1.0)	1.8 (1.8)	2.0 (2.8)	1.8 (1.8)	1.0 (1.0)
Approach, flare, and landing (17.2 - 17.3 ksec)	1.0 (1.0)	1.0 (1.0)	1.1 (1.1)	1.8 (1.0)	1.0 (1.0)	1.8 (1.8)	3.0 (3.8)[b]	1.8 (1.8)	2.0 (2.0)
	3	4	5	6	7	8	9	10	11

Flight number

NOTES: (a) Can be made $\leq$ 3.0 by deleting GN-6 on Flight 6 (value is decreased from 2954 to 2938).
(b) Can be made $\leq$ 3.0 by deleting FM-2, FM-13, and FM-14 on Flight 8 and GN-6 on Flight 9 (value is decreased from 3006 to 2972).

VI. SELECTED SYSTEM COSTS

A total cost of $1003 million has been estimated, by COCOM techniques, for the recommended flight research program, comprising 11 flights of the HL-10 D/3 entry vehicle, utilizing a Titan III-5 launch vehicle. Nonrecurring development costs of $470 million are included in the total.

The recommended program has approximately 10 percent greater cost/effectiveness than a curtailed or nominal program of seven flights involving a total cost of $853 million.

Detailed estimates are presented for (1) nonrecurring development costs, (2) the recommended flight research program, and (3) the nominal flight program, as well as (4) attainment of secondary objectives via a supercircular entry flight and a rendezvous and docking mission.

A. NONRECURRING DEVELOPMENT COSTS

The nonrecurring development costs are dependent on vehicle design and independent of the research program. The significant nonrecurring cost inputs developed from the system integration data of Part V and the selected vehicle design data of Part VII are given in table 26.

TABLE 26

NONRECURRING COST INPUTS

Subsystem nomenclature	Weight, lb	Weight, kg	Tooling rate capability, per yr	Ground test quantity*	Flight test quantity*
Structure	2672	(1212)	4	3.0	5.0
Heat shield	2710	(1230)	4	2.5	2.0
Surface control	946	(428)	4	5.0	4.0
Reaction control	185	(83.9)	4	4.0	1.0
Guidance and communication	532	(241)	4	4.0	1.0
Instrumentation	606	(275)	4	4.0	2.0
Research equipment	1030	(467)	(excluded by direction)		
Indirect vision	0	(0)	(provided for potential application)		

TABLE 26.--Concluded

NONRECURRING COST INPUTS

Subsystem nomenclature	Weight, lb	Weight, kg	Tooling rate capability, per yr	Ground test quantity*	Flight test quantity*
Environmental	435	(197)	4	4.0	1.0
Electrical	535	(243)	4	5.0	2.5
Instant L/D prop.	222	(101)	4	4.0	2.0
Landing gear	555	(252)	4	4.0	2.0
Emergency chutes	678	(307)	4	6.0	2.0
Crew provisions	240	(109)	4	3.0	2.0
Display panel	206	(93.4)	4	3.0	2.0
Adapter structure	510	(231)	4	3.0	2.0
Adapter environmental	0	(0)	(provided for potential application)		
Adapter electrical	0	(0)	(provided for potential application)		
Adapter deorbit prop.	1148	(520)	4	12.0	2.0
Adapter miscellaneous	100	(45.3)	4	3.0	2.0

*Note: quantity represents equivalent units; e.g., 3 half subsystems = 1.5

A breakdown of the $470 million development cost estimate is presented in table 27.

B. RECOMMENDED RESEARCH PROGRAM COSTS

The recommended research program consists of two unmanned and nine manned flights. Annual procurement, launch, and refurbishment schedules are shown in table 28. If more Tooling, AGE or facilities are required during the operational phase than were necessary during development, these additions are priced incrementally as needed and reported as recurring costs. Table 28 provides a detailed definition of the $1003 million estimated total cost. A cumulative total cost, including nonrecurring, is provided for the end of each operational year. Fiscal funding for the 11-flight plan is shown in table 29.

TABLE 27

NONRECURRING COSTS FOR RECOMMENDED PROGRAM

H L - 1 0   D / 3

OPERATIONAL SCHEDULE	1970	1971	1972	TOTALS
DELIVERIES...ENTRY VEHICLES	2	3	0	5
ADAPTERS	2	5	1	8
LAUNCHES	1	4	2	7
REFURBISHMENTS	0	2	1	3

1	NONRECURRING (DEVELOPMENT)	464925952.
2	MANAGEMENT	22139332.
3	DESIGN	151509984.
4	SYSTEM INTERFACE	6587390.
5	SUBSYSTEM INTEGRATION	13174780.
6	SUBSYSTEMS	131747808.
7	STRUCTURE	19789372.
8	HEAT SHIELD	22413388.
9	SURFACE CONTROL	5800496.
10	REACTION CONTROL	1684999.
11	GUID. & COMMUNICATION	22171784.
12	INSTRUMENTATION	4167599.
13	RESEARCH EQUIPMENT	0.
14	INDIRECT VISION	0.
15	ENVIRONMENTAL	20072288.
16	ELECTRICAL	9241952.
17	INSTANT L/D PROP.	287132.
18	LANDING GEAR	3177986.
19	EMERGENCY CHUTES	3264354.
20	CREW PROVISIONS	8910648.
21	DISPLAY PANEL	2519273.
22	ADAPTER STRUCTURE	6559901.
23	ADAPTER ENVIRONMENTAL	0.
24	ADAPTER ELECTRICAL	0.
25	ADAPTER DEORBIT PROP.	637468.
26	ADAPTER MISCELLANEOUS	1049308.
27	INITIAL TOOLING	28645152.
28	SUBSYSTEMS	28645152.
29	STRUCTURE	7766795.
30	HEAT SHIELD	8110109.
31	SURFACE CONTROL	828642.
32	REACTION CONTROL	288692.
33	GUID. & COMMUNICATION	969760.
34	INSTRUMENTATION	164360.
35	RESEARCH EQUIPMENT	0.
36	INDIRECT VISION	0.
37	ENVIRONMENTAL	1352997.
38	ELECTRICAL	1072114.
39	INSTANT L/D PROP.	136501.
40	LANDING GEAR	547928.
41	EMERGENCY CHUTES	457984.
42	CREW PROVISIONS	437528.
43	DISPLAY PANEL	226454.
44	ADAPTER STRUCTURE	2574585.
45	ADAPTER ENVIRONMENTAL	0.
46	ADAPTER ELECTRICAL	0.
47	ADAPTER DEORBIT PROP.	408213.
48	ADAPTER MISCELLANEOUS	68546.
49	ASSEMBLY	2545231.
50	ACCEPTANCE TEST	688730.
51	TOOL MAINTENANCE	4296772.
52	INITIAL A.G.E.	102875200.
53	MANUFACTURING SITE	47118496.
54	HANDLING EQUIPMENT	1690072.
55	STRUCTURE SERVICE	700733.
56	ELECTRONICS SERVICE	7603534.
57	MECHANICAL SERVICE	1186218.
58	ELECTRICAL SERVICE	2796111.
59	PROPULSION SERVICE	590390.
60	ENVIRONMENTAL SERVICE	3226137.
61	VERIFICATION SYSTEM	12613210.
62	INSTRUMENTATION	2871667.
63	SIMULATORS	5536171.
64	MISSION EQUIPMENT	8304257.
65	DROP TEST AREA	0.
66	HANDLING EQUIPMENT	0.
67	STRUCTURE SERVICE	0.
68	ELECTRONICS SERVICE	0.
69	MECHANICAL SERVICE	0.
70	ELECTRICAL SERVICE	0.
71	PROPULSION SERVICE	0.
72	ENVIRONMENTAL SERVICE	0.
73	VERIFICATION SYSTEM	0.
74	INSTRUMENTATION	0.
75	SIMULATORS	0.
76	MISSION EQUIPMENT	0.
77	CAPTIVE FIRING SITE	0.
78	HANDLING EQUIPMENT	0.
79	STRUCTURE SERVICE	0.
80	ELECTRONICS SERVICE	0.
81	MECHANICAL SERVICE	0.
82	ELECTRICAL SERVICE	0.
83	PROPULSION SERVICE	0.
84	ENVIRONMENTAL SERVICE	0.
85	VERIFICATION SYSTEM	0.
86	INSTRUMENTATION	0.
87	SIMULATORS	0.
88	MISSION EQUIPMENT	0.
89	LAUNCH AREA	41042496.
90	HANDLING EQUIPMENT	1515709.
91	STRUCTURE SERVICE	628440.
92	ELECTRONICS SERVICE	6612569.
93	MECHANICAL SERVICE	1031619.
94	ELECTRICAL SERVICE	2431695.
95	PROPULSION SERVICE	513445.
96	ENVIRONMENTAL SERVICE	2805676.
97	VERIFICATION SYSTEM	10969338.
98	INSTRUMENTATION	2497404.
99	SIMULATORS	4814644.
100	MISSION EQUIPMENT	7221967.
101	RECOVERY AREA	14714212.
102	HANDLING EQUIPMENT	1300066.
103	STRUCTURE SERVICE	0.
104	ELECTRONICS SERVICE	5431197.
105	MECHANICAL SERVICE	0.
106	ELECTRICAL SERVICE	0.
107	PROPULSION SERVICE	0.
108	ENVIRONMENTAL SERVICE	0.
109	VERIFICATION SYSTEM	0.
110	INSTRUMENTATION	2051229.
111	SIMULATORS	0.
112	MISSION EQUIPMENT	5931722.
113	REFURBISHMENT SITE	0.
114	HANDLING EQUIPMENT	0.
115	STRUCTURE SERVICE	0.
116	ELECTRONICS SERVICE	0.
117	MECHANICAL SERVICE	0.
118	ELECTRICAL SERVICE	0.

TABLE 27. --Concluded

NONRECURRING COSTS FOR RECOMMENDED PROGRAM

119	PROPULSION SERVICE	0.
120	ENVIRONMENTAL SERVICE	0.
121	VERIFICATION SYSTEM	0.
122	INSTRUMENTATION	0.
123	SIMULATORS	0.
124	MISSION EQUIPMENT	0.
125	A.G.E. MAINTENANCE	12859400.
126	GROUND TESTING	46187200.
127	STATIC TESTS	104124.
128	PROPULSION TESTS	313242.
129	INTEGRATED SYSTEM TESTS	101047.
130	TEST ARTICLES	45668792.
131	STRUCTURE	2539839.
132	HEAT SHIELD	2878764.
133	SURFACE CONTROL	1243586.
134	REACTION CONTROL	359658.
135	GUID. & COMMUNICATION	16689772.
136	INSTRUMENTATION	6142562.
137	RESEARCH EQUIPMENT	0.
138	INDIRECT VISION	0.
139	ENVIRONMENTAL	2493010.
140	ELECTRICAL	731098.
141	INSTANT L/D PROP.	177562.
142	LANDING GEAR	294766.
143	EMERGENCY CHUTES	5178553.
144	CREW PROVISIONS	534352.
145	DISPLAY PANEL	301266.
146	ADAPTER STRUCTURE	826174.
147	ADAPTER ENVIRONMENTAL	0.
148	ADAPTER ELECTRICAL	0.
149	ADAPTER DEORBIT PROP.	1178689.
150	ADAPTER MISCELLANEOUS	1021220.
151	ASSEMBLY	3077952.
152	ACCEPTANCE TEST	0.
153	SPACECRAFT SPARES	10934934.
154	FLIGHT TESTING	74328816.
155	AIR DROP FLIGHTS	6607041.
156	RECOVERY DROP	5526438.
157	PAD & MAX-Q ABORT	4555815.
158	UNMANNED ORBITAL	0.
159	MANNED ORBITAL	0.
160	TEST ARTICLES	27230788.
161	STRUCTURE	3755187.
162	HEAT SHIELD	2426730.
163	SURFACE CONTROL	1029191.
164	REACTION CONTROL	111005.
165	GUID. & COMMUNICATION	5151144.
166	INSTRUMENTATION	3232926.
167	RESEARCH EQUIPMENT	0.
168	INDIRECT VISION	0.
169	ENVIRONMENTAL	769444.
170	ELECTRICAL	406165.
171	INSTANT L/D PROP.	98645.
172	LANDING GEAR	163759.
173	EMERGENCY CHUTES	2039904.
174	CREW PROVISIONS	378880.
175	DISPLAY PANEL	213611.
176	ADAPTER STRUCTURE	605723.
177	ADAPTER ENVIRONMENTAL	0.
178	ADAPTER ELECTRICAL	0.
179	ADAPTER DEORBIT PROP.	257945.
180	ADAPTER MISCELLANEOUS	701550.
181	ASSEMBLY	3580770.
182	ACCEPTANCE TEST	2308235.
183	SPACECRAFT TRANSPORTING	4651.
184	LAUNCH VEHICLES	30404092.
185	ADAPTATION	26018460.
186	LITTLE JOE II	4385636.
187	TITAN III 2 SEG WO/TS	0.
188	TITAN III 2 SEG W/TS	0.
189	TITAN III 5 SEG WO/TS	0.
190	TITAN III 5 SEG W/TS	0.
191	MISSION SUPPORT	11149320.
192	INITIAL TRAINING	0.
193	INITIAL TRAINING EQUIP.	0.
194	NONRECURRING (FACILITIES)	5106302.
195	INSTALLATION (INITIAL)	4642093.
196	SPACECRAFT	4642093.
197	MANUFACTURING SITE	0.
198	DROP TEST AREA	0.
199	CAPTIVE FIRING SITE	0.
200	LAUNCH AREA	3704059.
201	RECOVERY AREA	938034.
202	REFURBISHMENT SITE	0.
203	MISSION CONTROL	0.
204	CENTRAL CONTROL	0.
205	LAND RANGE STATIONS	0.
206	SEA RANGE STATIONS	0.
207	MAINTENANCE	464209.
208	SPACECRAFT	464209.
209	MANUFACTURING SITE	0.
210	DROP TEST AREA	0.
211	CAPTIVE FIRING SITE	0.
212	LAUNCH AREA	370405.
213	RECOVERY AREA	93803.
214	REFURBISHMENT SITE	0.
215	MISSION CONTROL	0.
216	CENTRAL CONTROL	0.
217	LAND RANGE STATIONS	0.
218	SEA RANGE STATIONS	0.
	CUMULATIVE TOTAL COST	470032192.

F I S C A L   F U N D I N G

	YEAR	S/C CONTRACT	L/V COSTS	OTHER	TOTALS
1	1968	89760080.	5119942.	3615699.	98495712.
2	1969	277668352.	21539164.	26343532.	325551040.
3	1970	33804736.	3744978.	8435658.	45985368.

C U M U L A T I V E   F U N D S

	YEAR	S/C CONTRACT	L/V COSTS	OTHER	TOTALS
1	1968	89760080.	5119942.	3615699.	98495712.
2	1969	367428416.	26659104.	29959228.	424046720.
3	1970	401233088.	30404080.	38394888.	470032064.

TABLE 28
RECURRING COSTS FOR RECOMMENDED PROGRAM

H L - 1 0   D / 3

OPERATIONAL SCHEDULE	1970	1971	1972	TOTALS
DELIVERIES...ENTRY VEHICLES	2	3	1	6
ADAPTERS	2	5	5	12
LAUNCHES	1	4	6	11
REFURBISHMENTS	0	2	4	6

		YEAR 1970	YEAR 1971	YEAR 1972
1	RECURRING (OPERATIONAL)	97181280.	196073664.	234025760.
2	MANAGEMENT	5500827.	11098508.	13246740.
3	SUSTAINING ENGINEERING	30301992.	27271788.	24544608.
4	SPACECRAFT	32477096.	39281448.	14949832.
5	PROCUREMENT	28240036.	32403836.	10152370.
6	STRUCTURE	1879530.	1953220.	592924.
7	HEAT SHIELD	2449414.	2545447.	772702.
8	SURFACE CONTROL	577116.	693162.	219200.
9	REACTION CONTROL	201677.	242230.	76601.
10	GUID. & COMMUNICATION	9358748.	11240596.	3554633.
11	INSTRUMENTATION	3263146.	4456794.	1464330.
12	RESEARCH EQUIPMENT	0.	0.	0.
13	INDIRECT VISION	0.	0.	0.
14	ENVIRONMENTAL	1397949.	1679047.	530968.
15	ELECTRICAL	339284.	407507.	128866.
16	INSTANT L/D PROP.	99567.	119588.	37817.
17	LANDING GEAR	165289.	198526.	62780.
18	EMERGENCY CHUTES	2058972.	2472988.	782037.
19	CREW PROVISIONS	382422.	459319.	145251.
20	DISPLAY PANEL	215608.	258962.	81892.
21	ADAPTER STRUCTURE	611385.	635355.	192870.
22	ADAPTER ENVIRONMENTAL	0.	0.	0.
23	ADAPTER ELECTRICAL	0.	0.	0.
24	ADAPTER DEORBIT PROP.	260356.	312708.	98888.
25	ADAPTER MISCELLANEOUS	708108.	967132.	317762.
26	ASSEMBLY	1941664.	1709745.	496771.
27	ACCEPTANCE TEST	2329811.	2051531.	596078.
28	TRANSPORTATION	1057.	3718.	5273.
29	SPARES	4236005.	6873895.	4792191.
30	ADDITIONAL TOOLING	0.	0.	0.
31	TOOL MAINTENANCE	722822.	738885.	754949.
32	ADDITIONAL A.G.E.	0.	7378351.	12086430.
33	MANUFACTURING SITE	0.	0.	0.
34	DROP TEST AREA	0.	0.	0.
35	CAPTIVE FIRING SITE	0.	0.	0.
36	LAUNCH AREA	0.	5431201.	8896818.
37	RECOVERY AREA	0.	1947150.	3189612.
38	REFURBISHMENT SITE	0.	0.	0.
39	A.G.E. MAINTENANCE	2595920.	2843927.	3224292.
40	DROP TEST OPERATIONS	2683142.	2812290.	2416098.
41	CAPTIVE FIRING OPERATIONS	0.	0.	0.
42	LAUNCH OPERATIONS	1936168.	6805660.	9651814.
43	RECOVERY OPERATIONS	1161700.	4083395.	5791088.
44	REFURBISHMENT OPERATIONS	0.	8053281.	13077344.
45	STRUCTURE	0.	17712.	29636.
46	HEAT SHIELD	0.	2539156.	4248416.
47	SURFACE CONTROL	0.	55966.	100625.
48	REACTION CONTROL	0.	19558.	35164.
49	GUID. & COMMUNICATION	0.	90757.	163177.
50	INSTRUMENTATION	0.	48768.	93701.
51	RESEARCH EQUIPMENT	0.	0.	0.
52	INDIRECT VISION	0.	0.	0.
53	ENVIRONMENTAL	0.	13556.	24374.
54	ELECTRICAL	0.	32902.	59157.
55	INSTANT L/D PROP.	0.	91602.	144005.
56	LANDING GEAR	0.	16029.	28819.
57	EMERGENCY CHUTES	0.	599016.	1076996.
58	CREW PROVISIONS	0.	0.	0.
59	DISPLAY PANEL	0.	2090.	3759.
60	ADAPTER STRUCTURE	0.	624971.	842037.
61	ADAPTER ENVIRONMENTAL	0.	0.	0.
62	ADAPTER ELECTRICAL	0.	0.	0.
63	ADAPTER DEORBIT PROP.	0.	266141.	418394.
64	ADAPTER MISCELLANEOUS	0.	723844.	1305919.
65	ASSEMBLY	0.	887613.	1372992.
66	ACCEPTANCE TEST	0.	2023596.	3130173.
67	MISSION CONTROL OPERATIONS	1381509.	11179068.	22233956.
68	LAUNCH VEHICLES	18420124.	74527152.	112048656.
69	LITTLE JOE II	0.	0.	0.
70	TITAN III 2 SEG WO/TS	0.	0.	0.
71	TITAN III 2 SEG W/TS	0.	0.	0.
72	TITAN III 5 SEG WO/TS	18420124.	74527152.	112048656.
73	TITAN III 5 SEG W/TS	0.	0.	0.
74	TRAINING OPERATIONS	0.	0.	0.
75	ADDITIONAL TRAINING EQUIP.	0.	0.	0.
76	RECURRING (FACILITIES)	649571.	1652579.	3397736.
77	INSTALLATION (OPS. ADDIT.)	0.	941498.	2543997.
78	SPACECRAFT	0.	941498.	2117525.
79	MANUFACTURING SITE	0.	0.	0.
80	DROP TEST AREA	0.	0.	0.
81	CAPTIVE FIRING SITE	0.	0.	0.
82	LAUNCH AREA	0.	941498.	1771266.
83	RECOVERY AREA	0.	0.	346259.
84	REFURBISHMENT SITE	0.	0.	0.
85	MISSION CONTROL	0.	0.	426472.
86	CENTRAL CONTROL	0.	0.	85294.
87	LAND RANGE STATIONS	0.	0.	213236.
88	SEA RANGE STATIONS	0.	0.	127941.
89	MAINTENANCE	649571.	711081.	853739.
90	SPACECRAFT	468142.	525621.	642923.
91	MANUFACTURING SITE	205001.	209557.	214112.
92	DROP TEST AREA	0.	0.	0.
93	CAPTIVE FIRING SITE	0.	0.	0.
94	LAUNCH AREA	186934.	238163.	331903.
95	RECOVERY AREA	76206.	77900.	96906.
96	REFURBISHMENT SITE	0.	0.	0.
97	MISSION CONTROL	181428.	185460.	210815.
98	CENTRAL CONTROL	36285.	37092.	42163.
99	LAND RANGE STATIONS	90714.	92730.	105407.
00	SEA RANGE STATIONS	54428.	55638.	63244.
	CUMULATIVE TOTAL COST	567863041.	765589249.	1003012609.

TABLE 28. --Concluded

RECURRING COSTS FOR RECOMMENDED PROGRAM

	OPERATIONAL COSTS SUMMARY	
101	RECURRING (OPERATIONAL)	527280640.
102	MANAGEMENT	29846072.
103	SUSTAINING ENGINEERING	82118384.
104	SPACECRAFT	86708368.
105	PROCUREMENT	70796240.
106	STRUCTURE	4425674.
107	HEAT SHIELD	5767563.
108	SURFACE CONTROL	1489479.
109	REACTION CONTROL	520509.
110	GUID. & COMMUNICATION	24153976.
111	INSTRUMENTATION	9184270.
112	RESEARCH EQUIPMENT	0.
113	INDIRECT VISION	0.
114	ENVIRONMENTAL	3607965.
115	ELECTRICAL	875658.
116	INSTANT L/D PROP.	256974.
117	LANDING GEAR	426596.
118	EMERGENCY CHUTES	5313998.
119	CREW PROVISIONS	986993.
120	DISPLAY PANEL	556463.
121	ADAPTER STRUCTURE	1439610.
122	ADAPTER ENVIRONMENTAL	0.
123	ADAPTER ELECTRICAL	0.
124	ADAPTER DEORBIT PROP.	671952.
125	ADAPTER MISCELLANEOUS	1993003.
126	ASSEMBLY	4148180.
127	ACCEPTANCE TEST	4977421.
128	TRANSPORTATION	10049.
129	SPARES	15902090.
130	ADDITIONAL TOOLING	0.
131	TOOL MAINTENANCE	2216656.
132	ADDITIONAL A.G.E.	19464780.
133	MANUFACTURING SITE	0.
134	DROP TEST AREA	0.
135	CAPTIVE FIRING SITE	0.
136	LAUNCH AREA	14328018.
137	RECOVERY AREA	5136763.
138	REFURBISHMENT SITE	0.
139	A.G.E. MAINTENANCE	8664140.
140	DROP TEST OPERATIONS	7911529.
141	CAPTIVE FIRING OPERATIONS	0.
142	LAUNCH OPERATIONS	18393640.
143	RECOVERY OPERATIONS	11036184.
144	REFURBISHMENT OPERATIONS	21130624.
145	STRUCTURE	47348.
146	HEAT SHIELD	6787572.
147	SURFACE CONTROL	156591.
148	REACTION CONTROL	54722.
149	GUID. & COMMUNICATION	253935.
150	INSTRUMENTATION	142469.
151	RESEARCH EQUIPMENT	0.
152	INDIRECT VISION	0.
153	ENVIRONMENTAL	37931.
154	ELECTRICAL	92059.
155	INSTANT L/D PROP.	235607.
156	LANDING GEAR	44845.
157	EMERGENCY CHUTES	1676012.
158	CREW PROVISIONS	0.
159	DISPLAY PANEL	5850.
160	ADAPTER STRUCTURE	1467009.
161	ADAPTER ENVIRONMENTAL	0.
162	ADAPTER ELECTRICAL	0.
163	ADAPTER DEORBIT PROP.	584536.
164	ADAPTER MISCELLANEOUS	2029763.
165	ASSEMBLY	2260605.
166	ACCEPTANCE TEST	5153769.
167	MISSION CONTROL OPERATIONS	34794528.
168	LAUNCH VEHICLES	204995904.
169	LITTLE JOE II	0.
170	TITAN III 2 SEG WO/TS	0.
171	TITAN III 2 SEG W/TS	0.
172	TITAN III 5 SEG WO/TS	204995904.
173	TITAN III 5 SEG W/TS	0.
174	TRAINING OPERATIONS	0.
175	ADDITIONAL TRAINING EQUIP.	0.
176	RECURRING (FACILITIES)	5699886.
177	INSTALLATION (OPS. ADDIT.)	3485494.
178	SPACECRAFT	3059022.
179	MANUFACTURING SITE	0.
180	DROP TEST AREA	0.
181	CAPTIVE FIRING SITE	0.
182	LAUNCH AREA	2712764.
183	RECOVERY AREA	346259.
184	REFURBISHMENT SITE	0.
185	MISSION CONTROL	426472.
186	CENTRAL CONTROL	85294.
187	LAND RANGE STATIONS	213236.
188	SEA RANGE STATIONS	127941.
189	MAINTENANCE	2214391.
190	SPACECRAFT	1636687.
191	MANUFACTURING SITE	628672.
192	DROP TEST AREA	0.
193	CAPTIVE FIRING SITE	0.
194	LAUNCH AREA	757001.
195	RECOVERY AREA	251014.
196	REFURBISHMENT SITE	0.
197	MISSION CONTROL	577704.
198	CENTRAL CONTROL	115540.
199	LAND RANGE STATIONS	288852.
200	SEA RANGE STATIONS	173311.
	TOTAL OPERATIONAL COST	532980480.

TABLE 29

FISCAL FUNDING REQUIREMENTS: 11-FLIGHT PROGRAM

	1968	1969	1970	1971	1972
Nonrecurring	98×10^6	326×10^6	46×10^6		
Recurring		49	168	197×10^6	119×10^6
Total	98	375	214	197	119

Note that the fiscal funding rates lead the yearly rates, as shown by table 28. This lead accounts for work in process while the latter tables show cost accumulated by requirement. For example, if launch vehicles cost $20 million each, and two were launched in year 1970, then the printout would show $40 million for launch vehicles in year 1970; fiscal funding would require a goodly portion of this money in the prior year where it was actually spent or was in process of being spent. The fiscal funding detailed for nonrecurring is typical of a budget plan and correlates with the top line of table 27.

C. NOMINAL PROGRAM COSTS

The nominal research program costs estimated were for a 7-flight program, as required by Paragraph 4.2.7 of the Statement of Work dated September 15, 1965 on "Study of the Influence of Size of a Manned Lifting Body Entry Vehicle on Research Potential and Project Cost." The program consists of two unmanned and five manned flights. The annual procurement, launch and refurbishment schedules are shown in table 27. The 7-flight program total cost is estimated to be $853 million. Table 30 provides a detailed definition of this cost.

The following comparison demonstrates the increased cost effectiveness obtained with the more costly recommended program.

	11 flight	7 flight
Experiments assigned	50	44
Value produced	2954	2257
Cost/effectiveness (million dollars)	3.0	2.7
Cost (million dollars/unit value)	1003	853

TABLE 30

RECURRING COSTS FOR NOMINAL PROGRAM

		YEAR 1970	YEAR 1971	YEAR 1972
1	RECURRING (OPERATIONAL)	97181280.	194974400.	88591120.
2	MANAGEMENT	5500827.	11036286.	5014592.
3	SUSTAINING ENGINEERING	30301992.	27271788.	24544608.
4	SPACECRAFT	32477096.	39281448.	866386.
5	PROCUREMENT	28240036.	32403836.	0.
6	STRUCTURE	1879530.	1953220.	0.
7	HEAT SHIELD	2449414.	2545447.	0.
8	SURFACE CONTROL	577116.	693162.	0.
9	REACTION CONTROL	201677.	242230.	0.
10	GUID. & COMMUNICATION	9358748.	11240596.	0.
11	INSTRUMENTATION	3263146.	4456794.	0.
12	RESEARCH EQUIPMENT	0.	0.	0.
13	INDIRECT VISION	0.	0.	0.
14	ENVIRONMENTAL	1397949.	1679047.	0.
15	ELECTRICAL	339284.	407507.	0.
16	INSTANT L/D PROP.	99567.	119588.	0.
17	LANDING GEAR	165289.	198526.	0.
18	EMERGENCY CHUTES	2058972.	2472988.	0.
19	CREW PROVISIONS	382422.	459319.	0.
20	DISPLAY PANEL	215608.	258962.	0.
21	ADAPTER STRUCTURE	611385.	635355.	0.
22	ADAPTER ENVIRONMENTAL	0.	0.	0.
23	ADAPTER ELECTRICAL	0.	0.	0.
24	ADAPTER DEORBIT PROP.	260356.	312708.	0.
25	ADAPTER MISCELLANEOUS	708108.	967132.	0.
26	ASSEMBLY	1941664.	1709745.	0.
27	ACCEPTANCE TEST	2329811.	2051531.	0.
28	TRANSPORTATION	1057.	3718.	1792.
29	SPARES	4236005.	6873895.	864593.
30	ADDITIONAL TOOLING	0.	0.	0.
31	TOOL MAINTENANCE	722822.	738885.	754948.
32	ADDITIONAL A.G.E.	0.	7378351.	0.
33	MANUFACTURING SITE	0.	0.	0.
34	DROP TEST AREA	0.	0.	0.
35	CAPTIVE FIRING SITE	0.	0.	0.
36	LAUNCH AREA	0.	5431201.	0.
37	RECOVERY AREA	0.	1947150.	0.
38	REFURBISHMENT SITE	0.	0.	0.
39	A.G.E. MAINTENANCE	2595920.	2843927.	2905752.
40	DROP TEST OPERATIONS	2683142.	1775271.	708290.
41	CAPTIVE FIRING OPERATIONS	0.	0.	0.
42	LAUNCH OPERATIONS	1936168.	6805660.	3281308.
43	RECOVERY OPERATIONS	1161700.	4083395.	1968784.
44	REFURBISHMENT OPERATIONS	0.	8053281.	3458375.
45	STRUCTURE	0.	17712.	7789.
46	HEAT SHIELD	0.	2539156.	1116574.
47	SURFACE CONTROL	0.	55966.	25986.
48	REACTION CONTROL	0.	19558.	9081.
49	GUID. & COMMUNICATION	0.	90757.	42144.
50	INSTRUMENTATION	0.	48768.	23801.
51	RESEARCH EQUIPMENT	0.	0.	0.
52	INDIRECT VISION	0.	0.	0.
53	ENVIRONMENTAL	0.	13556.	6295.
54	ELECTRICAL	0.	32902.	15278.
55	INSTANT L/D PROP.	0.	91602.	38405.
56	LANDING GEAR	0.	16029.	7443.
57	EMERGENCY CHUTES	0.	599016.	278160.
58	CREW PROVISIONS	0.	0.	0.
59	DISPLAY PANEL	0.	2090.	970.
60	ADAPTER STRUCTURE	0.	624971.	232401.
61	ADAPTER ENVIRONMENTAL	0.	0.	0.
62	ADAPTER ELECTRICAL	0.	0.	0.
63	ADAPTER DEORBIT PROP.	0.	266141.	111584.
64	ADAPTER MISCELLANEOUS	0.	723844.	336998.
65	ASSEMBLY	0.	887613.	367538.
66	ACCEPTANCE TEST	0.	2023596.	837919.
67	MISSION CONTROL OPERATIONS	1331509.	11179068.	7465504.
68	LAUNCH VEHICLES	18420124.	74527152.	37622624.
69	LITTLE JOE II	0.	0.	0.
70	TITAN III 2 SEG WO/TS	0.	0.	0.
71	TITAN III 2 SEG W/TS	0.	0.	0.
72	TITAN III 5 SEG WO/TS	18420124.	74527152.	37622624.
73	TITAN III 5 SEG W/TS	0.	0.	0.
74	TRAINING OPERATIONS	0.	0.	0.
75	ADDITIONAL TRAINING EQUIP.	0.	0.	0.
76	RECURRING (FACILITIES)	649571.	1652579.	726539.
77	INSTALLATION (OPS. ADDIT.)	0.	941498.	0.
78	SPACECRAFT	0.	941498.	0.
79	MANUFACTURING SITE	0.	0.	0.
80	DROP TEST AREA	0.	0.	0.
81	CAPTIVE FIRING SITE	0.	0.	0.
82	LAUNCH AREA	0.	941498.	0.
83	RECOVERY AREA	0.	0.	0.
84	REFURBISHMENT SITE	0.	0.	0.
85	MISSION CONTROL	0.	0.	0.
86	CENTRAL CONTROL	0.	0.	0.
87	LAND RANGE STATIONS	0.	0.	0.
88	SEA RANGE STATIONS	0.	0.	0.
89	MAINTENANCE	649571.	711081.	726539.
90	SPACECRAFT	468142.	525621.	537047.
91	MANUFACTURING SITE	205001.	209557.	214112.
92	DROP TEST AREA	0.	0.	0.
93	CAPTIVE FIRING SITE	0.	0.	0.
94	LAUNCH AREA	186934.	238163.	243340.
95	RECOVERY AREA	76206.	77900.	79593.
96	REFURBISHMENT SITE	0.	0.	0.
97	MISSION CONTROL	181428.	185460.	189491.
98	CENTRAL CONTROL	36285.	37092.	37898.
99	LAND RANGE STATIONS	90714.	92730.	94745.
100	SEA RANGE STATIONS	54428.	55638.	56847.
	CUMULATIVE TOTAL COST	567863041.	764489985.	853807617.

TABLE 30. --Concluded
RECURRING COSTS FOR NOMINAL PROGRAM

OPERATIONAL COSTS SUMMARY

101	RECURRING (OPERATIONAL)	380746752.
102	MANAGEMENT	21551704.
103	SUSTAINING ENGINEERING	82118384.
104	SPACECRAFT	72624928.
105	PROCUREMENT	60643872.
106	STRUCTURE	3832750.
107	HEAT SHIELD	4994861.
108	SURFACE CONTROL	1270279.
109	REACTION CONTROL	443908.
110	GUID. & COMMUNICATION	20599344.
111	INSTRUMENTATION	7719940.
112	RESEARCH EQUIPMENT	0.
113	INDIRECT VISION	0.
114	ENVIRONMENTAL	3076997.
115	ELECTRICAL	746791.
116	INSTANT L/D PROP.	219156.
117	LANDING GEAR	363815.
118	EMERGENCY CHUTES	4531961.
119	CREW PROVISIONS	841742.
120	DISPLAY PANEL	474571.
121	ADAPTER STRUCTURE	1246740.
122	ADAPTER ENVIRONMENTAL	0.
123	ADAPTER ELECTRICAL	0.
124	ADAPTER DEORBIT PROP.	573064.
125	ADAPTER MISCELLANEOUS	1675241.
126	ASSEMBLY	3651409.
127	ACCEPTANCE TEST	4381343.
128	TRANSPORTATION	6568.
129	SPARES	11974492.
130	ADDITIONAL TOOLING	0.
131	TOOL MAINTENANCE	2216656.
132	ADDITIONAL A.G.E.	7378351.
133	MANUFACTURING SITE	0.
134	DROP TEST AREA	0.
135	CAPTIVE FIRING SITE	0.
136	LAUNCH AREA	5431201.
137	RECOVERY AREA	1947150.
138	REFURBISHMENT SITE	0.
139	A.G.E. MAINTENANCE	8345598.
140	DROP TEST OPERATIONS	5166703.
141	CAPTIVE FIRING OPERATIONS	0.
142	LAUNCH OPERATIONS	12023134.
143	RECOVERY OPERATIONS	7213880.
144	REFURBISHMENT OPERATIONS	11511656.
145	STRUCTURE	25501.
146	HEAT SHIELD	3655731.
147	SURFACE CONTROL	81955.
148	REACTION CONTROL	28639.
149	GUID. & COMMUNICATION	132902.
150	INSTRUMENTATION	72569.
151	RESEARCH EQUIPMENT	0.
152	INDIRECT VISION	0.
153	ENVIRONMENTAL	19852.
154	ELECTRICAL	48181.
155	INSTANT L/D PROP.	130007.
156	LANDING GEAR	23472.
157	EMERGENCY CHUTES	877176.
158	CREW PROVISIONS	0.
159	DISPLAY PANEL	3061.
160	ADAPTER STRUCTURE	857373.
161	ADAPTER ENVIRONMENTAL	0.
162	ADAPTER ELECTRICAL	0.
163	ADAPTER DEORBIT PROP.	377725.
164	ADAPTER MISCELLANEOUS	1060842.
165	ASSEMBLY	1255151.
166	ACCEPTANCE TEST	2861516.
167	MISSION CONTROL OPERATIONS	20026080.
168	LAUNCH VEHICLES	130569872.
169	LITTLE JOE II	0.
170	TITAN III 2 SEG WO/TS	0.
171	TITAN III 2 SEG W/TS	0.
172	TITAN III 5 SEG WO/TS	130569872.
173	TITAN III 5 SEG W/TS	0.
174	TRAINING OPERATIONS	0.
175	ADDITIONAL TRAINING EQUIP.	0.
176	RECURRING (FACILITIES)	3028689.
177	INSTALLATION (OPS. ADDIT.)	941498.
178	SPACECRAFT	941498.
179	MANUFACTURING SITE	0.
180	DROP TEST AREA	0.
181	CAPTIVE FIRING SITE	0.
182	LAUNCH AREA	941498.
183	RECOVERY AREA	0.
184	REFURBISHMENT SITE	0.
185	MISSION CONTROL	0.
186	CENTRAL CONTROL	0.
187	LAND RANGE STATIONS	0.
188	SEA RANGE STATIONS	0.
189	MAINTENANCE	2087191.
190	SPACECRAFT	1530811.
191	MANUFACTURING SITE	628672.
192	DROP TEST AREA	0.
193	CAPTIVE FIRING SITE	0.
194	LAUNCH AREA	668437.
195	RECOVERY AREA	233701.
196	REFURBISHMENT SITE	0.
197	MISSION CONTROL	556380.
198	CENTRAL CONTROL	111276.
199	LAND RANGE STATIONS	278190.
200	SEA RANGE STATIONS	166914.
	TOTAL OPERATIONAL COST	383775424.

D. SECONDARY OBJECTIVE COSTS

Incremental program costs were estimated for one supercircular entry flight and one rendezvous and docking mission. These estimates assume, in each case, that the 11-flight program would be extended by one flight to accomplish the desired experiments. For the additional flight the entry vehicle from flight number eight would be refurbished and re-equipped.

The significant inputs for the supercircular entry mission follow:

(1) Removal of the aft crew station (seat, displays)

(2) Installation of a thicker heat shield

(3) Installation of instrumentation for radiative heating measurements

(4) Refurbishment of all other subsystems

(5) One complete launch-recovery operation

(6)

Subsystem	Weight, lb	Weight, kg	Tooling rate capability, per yr	Ground test quantity	Flight test quantity
Heat shield	3160	1433	1	1.1	-
Instrumentation	300	136	1	0.5	-

The significant inputs for the rendezvous and docking mission follow:

(1) Removal of aft bulkhead center panel and installation of tunnel assembly.

(2) Refurbishment of all subsystems; relocation of the instant L/D motors, braking chute, rudder actuator and one antenna.

(3)

Subsystem	Weight, lb	Weight, kg	Tooling rate capability, per yr	Ground test quantity	Flight test quantity
Structure	30	13.6	1	3.0	-

The additional supercircular mission cost is estimated to be $45.94 million. Detailed identification of the cost elements is given in table 31. The rendezvous and docking mission cost is estimated to be $33.57 million, with details given in table 32. Each of these estimates is predicated upon extending the program duration and maintaining the established launch rate. If the increased mission can be included within the initial span, the sustaining engineering and various maintenance costs could be eliminated and the management cost considerably reduced. However, these costs have been included since increasing the time span is believed to be a more realistic approach.

TABLE 31

HL-10 D/3 MODIFICATION FOR SUPERORBITAL ENTRY

1	NONRECURRING (DEVELOPMENT)	10273628.
2	MANAGEMENT	489220.
3	DESIGN	4764176.
4	SYSTEM INTERFACE	207138.
5	SUBSYSTEM INTEGRATION	414276.
6	SUBSYSTEMS	4142761.
7	STRUCTURE	0.
8	HEAT SHIELD	3839667.
9	SURFACE CONTROL	0.
10	REACTION CONTROL	0.
11	GUID. & COMMUNICATION	0.
12	INSTRUMENTATION	303094.
13	RESEARCH EQUIPMENT	0.
14	INDIRECT VISION	0.
15	ENVIRONMENTAL	0.
16	ELECTRICAL	0.
17	INSTANT L/D PROP.	0.
18	LANDING GEAR	0.
19	EMERGENCY CHUTES	0.
20	CREW PROVISIONS	0.
21	DISPLAY PANEL	0.
22	ADAPTER STRUCTURE	0.
23	ADAPTER ENVIRONMENTAL	0.
24	ADAPTER ELECTRICAL	0.
25	ADAPTER DEORBIT PROP.	0.
26	ADAPTER MISCELLANEOUS	0.
27	INITIAL TOOLING	1793443.
28	SUBSYSTEMS	1793443.
29	STRUCTURE	0.
30	HEAT SHIELD	1775878.
31	SURFACE CONTROL	0.
32	REACTION CONTROL	0.
33	GUID. & COMMUNICATION	0.
34	INSTRUMENTATION	17565.
35	RESEARCH EQUIPMENT	0.
36	INDIRECT VISION	0.
37	ENVIRONMENTAL	0.
38	ELECTRICAL	0.
39	INSTANT L/D PROP.	0.
40	LANDING GEAR	0.
41	EMERGENCY CHUTES	0.
42	CREW PROVISIONS	0.
43	DISPLAY PANEL	0.
44	ADAPTER STRUCTURE	0.
45	ADAPTER ENVIRONMENTAL	0.
46	ADAPTER ELECTRICAL	0.
47	ADAPTER DEORBIT PROP.	0.
48	ADAPTER MISCELLANEOUS	0.
49	ASSEMBLY	0.
50	ACCEPTANCE TEST	0.
51	TOOL MAINTENANCE	269016.
52	INITIAL A.G.E.	0.
53	MANUFACTURING SITE	0.
54	HANDLING EQUIPMENT	0.
55	STRUCTURE SERVICE	0.
56	ELECTRONICS SERVICE	0.
57	MECHANICAL SERVICE	0.
58	ELECTRICAL SERVICE	0.
59	PROPULSION SERVICE	0.
60	ENVIRONMENTAL SERVICE	0.
61	VERIFICATION SYSTEM	0.
62	INSTRUMENTATION	0.
63	SIMULATORS	0.
64	MISSION EQUIPMENT	0.
65	DROP TEST AREA	0.
66	HANDLING EQUIPMENT	0.
67	STRUCTURE SERVICE	0.
68	ELECTRONICS SERVICE	0.
69	MECHANICAL SERVICE	0.
70	ELECTRICAL SERVICE	0.
71	PROPULSION SERVICE	0.
72	ENVIRONMENTAL SERVICE	0.
73	VERIFICATION SYSTEM	0.
74	INSTRUMENTATION	0.
75	SIMULATORS	0.
76	MISSION EQUIPMENT	0.
77	CAPTIVE FIRING SITE	0.
78	HANDLING EQUIPMENT	0.
79	STRUCTURE SERVICE	0.
80	ELECTRONICS SERVICE	0.
81	MECHANICAL SERVICE	0.
82	ELECTRICAL SERVICE	0.
83	PROPULSION SERVICE	0.
84	ENVIRONMENTAL SERVICE	0.
85	VERIFICATION SYSTEM	0.
86	INSTRUMENTATION	0.
87	SIMULATORS	0.
88	MISSION EQUIPMENT	0.
89	LAUNCH AREA	0.
90	HANDLING EQUIPMENT	0.
91	STRUCTURE SERVICE	0.
92	ELECTRONICS SERVICE	0.
93	MECHANICAL SERVICE	0.
94	ELECTRICAL SERVICE	0.
95	PROPULSION SERVICE	0.
96	ENVIRONMENTAL SERVICE	0.
97	VERIFICATION SYSTEM	0.
98	INSTRUMENTATION	0.
99	SIMULATORS	0.
00	MISSION EQUIPMENT	0.
01	RECOVERY AREA	0.
02	HANDLING EQUIPMENT	0.
03	STRUCTURE SERVICE	0.
04	ELECTRONICS SERVICE	0.
05	MECHANICAL SERVICE	0.
06	ELECTRICAL SERVICE	0.
07	PROPULSION SERVICE	0.
08	ENVIRONMENTAL SERVICE	0.
09	VERIFICATION SYSTEM	0.
110	INSTRUMENTATION	0.
111	SIMULATORS	0.
112	MISSION EQUIPMENT	0.
113	REFURBISHMENT SITE	0.
114	HANDLING EQUIPMENT	0.
115	STRUCTURE SERVICE	0.
116	ELECTRONICS SERVICE	0.
117	MECHANICAL SERVICE	0.
118	ELECTRICAL SERVICE	0.
119	PROPULSION SERVICE	0.

TABLE 31. --Continued

HL-10 D/3 MODIFICATION FOR SUPERORBITAL ENTRY

120	ENVIRONMENTAL SERVICE	0.
121	VERIFICATION SYSTEM	0.
122	INSTRUMENTATION	0.
123	SIMULATORS	0.
124	MISSION EQUIPMENT	0.
125	A.G.E. MAINTENANCE	0.
126	GROUND TESTING	2571979.
127	STATIC TESTS	0.
128	PROPULSION TESTS	0.
129	INTEGRATED SYSTEM TESTS	0.
130	TEST ARTICLES	2571979.
131	STRUCTURE	0.
132	HEAT SHIELD	1624542.
133	SURFACE CONTROL	0.
134	REACTION CONTROL	0.
135	GUID. & COMMUNICATION	0.
136	INSTRUMENTATION	947436.
137	RESEARCH EQUIPMENT	0.
138	INDIRECT VISION	0.
139	ENVIRONMENTAL	0.
140	ELECTRICAL	0.
141	INSTANT L/D PROP.	0.
142	LANDING GEAR	0.
143	EMERGENCY CHUTES	0.
144	CREW PROVISIONS	0.
145	DISPLAY PANEL	0.
146	ADAPTER STRUCTURE	0.
147	ADAPTER ENVIRONMENTAL	0.
148	ADAPTER ELECTRICAL	0.
149	ADAPTER DEORBIT PROP.	0.
150	ADAPTER MISCELLANEOUS	0.
151	ASSEMBLY	0.
152	ACCEPTANCE TEST	0.
153	SPACECRAFT SPARES	385796.
154	FLIGHT TESTING	0.
155	AIR DROP FLIGHTS	0.
156	RECOVERY DROP	0.
157	PAD & MAX-Q ABORT	0.
158	UNMANNED ORBITAL	0.
159	MANNED ORBITAL	0.
160	TEST ARTICLES	0.
161	STRUCTURE	0.
162	HEAT SHIELD	0.
163	SURFACE CONTROL	0.
164	REACTION CONTROL	0.
165	GUID. & COMMUNICATION	0.
166	INSTRUMENTATION	0.
167	RESEARCH EQUIPMENT	0.
168	INDIRECT VISION	0.
169	ENVIRONMENTAL	0.
170	ELECTRICAL	0.
171	INSTANT L/D PROP.	0.
172	LANDING GEAR	0.
173	EMERGENCY CHUTES	0.
174	CREW PROVISIONS	0.
175	DISPLAY PANEL	0.
176	ADAPTER STRUCTURE	0.
177	ADAPTER ENVIRONMENTAL	0.
178	ADAPTER ELECTRICAL	0.
179	ADAPTER DEORBIT PROP.	0.
180	ADAPTER MISCELLANEOUS	0.
181	ASSEMBLY	0.
182	ACCEPTANCE TEST	0.
183	SPACECRAFT TRANSPORTING	0.
184	LAUNCH VEHICLES	0.
185	ADAPTATION	0.
186	LITTLE JOE II	0.
187	TITAN III 2 SEG WO/TS	0.
188	TITAN III 2 SEG W/TS	0.
189	TITAN III 5 SEG WO/TS	0.
190	TITAN III 5 SEG W/TS	0.
191	MISSION SUPPORT	0.
192	INITIAL TRAINING	0.
193	INITIAL TRAINING EQUIP.	0.
194	NONRECURRING (FACILITIES)	0.
195	INSTALLATION (INITIAL)	0.
196	SPACECRAFT	0.
197	MANUFACTURING SITE	0.
198	DROP TEST AREA	0.
199	CAPTIVE FIRING SITE	0.
200	LAUNCH AREA	0.
201	RECOVERY AREA	0.
202	REFURBISHMENT SITE	0.
203	MISSION CONTROL	0.
204	CENTRAL CONTROL	0.
205	LAND RANGE STATIONS	0.
206	SEA RANGE STATIONS	0.
207	MAINTENANCE	0.
208	SPACECRAFT	0.
209	MANUFACTURING SITE	0.
210	DROP TEST AREA	0.
211	CAPTIVE FIRING SITE	0.
212	LAUNCH AREA	0.
213	RECOVERY AREA	0.
214	REFURBISHMENT SITE	0.
215	MISSION CONTROL	0.
216	CENTRAL CONTROL	0.
217	LAND RANGE STATIONS	0.
218	SEA RANGE STATIONS	0.
	CUMULATIVE TOTAL COST	10273628.

F I S C A L   F U N D I N G

	YEAR	S/C CONTRACT	L/V COSTS	OTHER	TOTALS
1	1971	4929948.	0.	117208.	5047156.
2	1972	4854456.	0.	372013.	5226469.

C U M U L A T I V E   F U N D S

	YEAR	S/C CONTRACT	L/V COSTS	OTHER	TOTALS
1	1971	4929948.	0.	117208.	5047156.
2	1972	9784404.	0.	489221.	10273624.

TABLE 31. --Continued

HL-10 D/3 MODIFICATION FOR SUPERORBITAL ENTRY

		YEAR 1972
1	RECURRING (OPERATIONAL)	35329472.
2	MANAGEMENT	1999781.
3	SUSTAINING ENGINEERING	952835.
4	SPACECRAFT	1395288.
5	PROCUREMENT	0.
6	STRUCTURE	0.
7	HEAT SHIELD	0.
8	SURFACE CONTROL	0.
9	REACTION CONTROL	0.
10	GUID. & COMMUNICATION	0.
11	INSTRUMENTATION	0.
12	RESEARCH EQUIPMENT	0.
13	INDIRECT VISION	0.
14	ENVIRONMENTAL	0.
15	ELECTRICAL	0.
16	INSTANT L/D PROP.	0.
17	LANDING GEAR	0.
18	EMERGENCY CHUTES	0.
19	CREW PROVISIONS	0.
20	DISPLAY PANEL	0.
21	ADAPTER STRUCTURE	0.
22	ADAPTER ENVIRONMENTAL	0.
23	ADAPTER ELECTRICAL	0.
24	ADAPTER DEORBIT PROP.	0.
25	ADAPTER MISCELLANEOUS	0.
26	ASSEMBLY	0.
27	ACCEPTANCE TEST	0.
28	TRANSPORTATION	1104.
29	SPARES	1394184.
30	ADDITIONAL TOOLING	0.
31	TOOL MAINTENANCE	44677.
32	ADDITIONAL A.G.E.	0.
33	MANUFACTURING SITE	0.
34	DROP TEST AREA	0.
35	CAPTIVE FIRING SITE	0.
36	LAUNCH AREA	0.
37	RECOVERY AREA	0.
38	REFURBISHMENT SITE	0.
39	A.G.E. MAINTENANCE	0.
40	DROP TEST OPERATIONS	0.
41	CAPTIVE FIRING OPERATIONS	0.
42	LAUNCH OPERATIONS	2022219.
43	RECOVERY OPERATIONS	1213331.
44	REFURBISHMENT OPERATIONS	5576736.
45	STRUCTURE	9814.
46	HEAT SHIELD	1619277.
47	SURFACE CONTROL	30138.
48	REACTION CONTROL	10532.
49	GUID. & COMMUNICATION	48873.
50	INSTRUMENTATION	869084.
51	RESEARCH EQUIPMENT	0.
52	INDIRECT VISION	0.
53	ENVIRONMENTAL	7300.
54	ELECTRICAL	17718.
55	INSTANT L/D PROP.	51996.
56	LANDING GEAR	8631.
57	EMERGENCY CHUTES	322572.
58	CREW PROVISIONS	998.
59	DISPLAY PANEL	1125.
60	ADAPTER STRUCTURE	375631.
61	ADAPTER ENVIRONMENTAL	0.
62	ADAPTER ELECTRICAL	0.

		Year 1972
63	ADAPTER DEORBIT PROP.	151070.
64	ADAPTER MISCELLANEOUS	389252.
65	ASSEMBLY	506955.
66	ACCEPTANCE TEST	1155765.
67	MISSION CONTROL OPERATIONS	2885818.
68	LAUNCH VEHICLES	19238796.
69	LITTLE JOE II	0.
70	TITAN III 2 SEG WO/TS	0.
71	TITAN III 2 SEG W/TS	0.
72	TITAN III 5 SEG WO/TS	19238796.
73	TITAN III 5 SEG W/TS	0.
74	TRAINING OPERATIONS	0.
75	ADDITIONAL TRAINING EQUIP.	0.
76	RECURRING (FACILITIES)	340048.
77	INSTALLATION (OPS. ADDIT.)	0.
78	SPACECRAFT	0.
79	MANUFACTURING SITE	0.
80	DROP TEST AREA	0.
81	CAPTIVE FIRING SITE	0.
82	LAUNCH AREA	0.
83	RECOVERY AREA	0.
84	REFURBISHMENT SITE	0.
85	MISSION CONTROL	0.
86	CENTRAL CONTROL	0.
87	LAND RANGE STATIONS	0.
88	SEA RANGE STATIONS	0.
89	MAINTENANCE	340048.
90	SPACECRAFT	208450.
91	MANUFACTURING SITE	83634.
92	DROP TEST AREA	0.
93	CAPTIVE FIRING SITE	0.
94	LAUNCH AREA	84204.
95	RECOVERY AREA	40610.
96	REFURBISHMENT SITE	0.
97	MISSION CONTROL	131597.
98	CENTRAL CONTROL	26319.
99	LAND RANGE STATIONS	65798.
100	SEA RANGE STATIONS	39479.
	CUMULATIVE TOTAL COST	45943144.

TABLE 31. --Concluded

HL-10 D/3 MODIFICATION FOR SUPERORBITAL ENTRY

OPERATIONAL COSTS SUMMARY

101	RECURRING (OPERATIONAL)	35329472.
102	MANAGEMENT	1999781.
103	SUSTAINING ENGINEERING	952835.
104	SPACECRAFT	1395288.
105	PROCUREMENT	0.
106	STRUCTURE	0.
107	HEAT SHIELD	0.
108	SURFACE CONTROL	0.
109	REACTION CONTROL	0.
110	GUID. & COMMUNICATION	0.
111	INSTRUMENTATION	0.
112	RESEARCH EQUIPMENT	0.
113	INDIRECT VISION	0.
114	ENVIRONMENTAL	0.
115	ELECTRICAL	0.
116	INSTANT L/D PROP.	0.
117	LANDING GEAR	0.
118	EMERGENCY CHUTES	0.
119	CREW PROVISIONS	0.
120	DISPLAY PANEL	0.
121	ADAPTER STRUCTURE	0.
122	ADAPTER ENVIRONMENTAL	0.
123	ADAPTER ELECTRICAL	0.
124	ADAPTER DEORBIT PROP.	0.
125	ADAPTER MISCELLANEOUS	0.
126	ASSEMBLY	0.
127	ACCEPTANCE TEST	0.
128	TRANSPORTATION	1104.
129	SPARES	1394184.
130	ADDITIONAL TOOLING	0.
131	TOOL MAINTENANCE	44677.
132	ADDITIONAL A.G.E.	0.
133	MANUFACTURING SITE	0.
134	DROP TEST AREA	0.
135	CAPTIVE FIRING SITE	0.
136	LAUNCH AREA	0.
137	RECOVERY AREA	0.
138	REFURBISHMENT SITE	0.
139	A.G.E. MAINTENANCE	0.
140	DROP TEST OPERATIONS	0.
141	CAPTIVE FIRING OPERATIONS	0.
142	LAUNCH OPERATIONS	2022219.
143	RECOVERY OPERATIONS	1213331.
144	REFURBISHMENT OPERATIONS	5576736.
145	STRUCTURE	9814.
146	HEAT SHIELD	1619277.
147	SURFACE CONTROL	30138.
148	REACTION CONTROL	10532.
149	GUID. & COMMUNICATION	48873.
150	INSTRUMENTATION	869084.
151	RESEARCH EQUIPMENT	0.
152	INDIRECT VISION	0.
153	ENVIRONMENTAL	7300.
154	ELECTRICAL	17718.
155	INSTANT L/D PROP.	51996.
156	LANDING GEAR	8631.
157	EMERGENCY CHUTES	322572.
158	CREW PROVISIONS	998.
159	DISPLAY PANEL	1125.
160	ADAPTER STRUCTURE	375631.
161	ADAPTER ENVIRONMENTAL	0.
162	ADAPTER ELECTRICAL	0.
163	ADAPTER DEORBIT PROP.	151070.
164	ADAPTER MISCELLANEOUS	389252.
165	ASSEMBLY	506955.
166	ACCEPTANCE TEST	1155765.
167	MISSION CONTROL OPERATIONS	2885818.
168	LAUNCH VEHICLES	19238796.
169	LITTLE JOE II	0.
170	TITAN III 2 SEG WO/TS	0.
171	TITAN III 2 SEG W/TS	0.
172	TITAN III 5 SEG WO/TS	19238796.
173	TITAN III 5 SEG W/TS	0.
174	TRAINING OPERATIONS	0.
175	ADDITIONAL TRAINING EQUIP.	0.
176	RECURRING (FACILITIES)	340048.
177	INSTALLATION (OPS. ADDIT.)	0.
178	SPACECRAFT	0.
179	MANUFACTURING SITE	0.
180	DROP TEST AREA	0.
181	CAPTIVE FIRING SITE	0.
182	LAUNCH AREA	0.
183	RECOVERY AREA	0.
184	REFURBISHMENT SITE	0.
185	MISSION CONTROL	0.
186	CENTRAL CONTROL	0.
187	LAND RANGE STATIONS	0.
188	SEA RANGE STATIONS	0.
189	MAINTENANCE	340048.
190	SPACECRAFT	208450.
191	MANUFACTURING SITE	83634.
192	DROP TEST AREA	0.
193	CAPTIVE FIRING SITE	0.
194	LAUNCH AREA	84204.
195	RECOVERY AREA	40610.
196	REFURBISHMENT SITE	0.
197	MISSION CONTROL	131597.
198	CENTRAL CONTROL	26319.
199	LAND RANGE STATIONS	65798.
200	SEA RANGE STATIONS	39479.
	TOTAL OPERATIONAL COST	35669520.

TABLE 32

HL-10 D/3 MODIFICATION FOR RENDEZVOUS AND DOCKING

1	NONRECURRING (DEVELOPMENT)	298904.
2	MANAGEMENT	14233.
3	DESIGN	183925.
4	SYSTEM INTERFACE	7996.
5	SUBSYSTEM INTEGRATION	15993.
6	SUBSYSTEMS	159935.
7	STRUCTURE	159935.
8	HEAT SHIELD	0.
9	SURFACE CONTROL	0.
10	REACTION CONTROL	0.
11	GUID. & COMMUNICATION	0.
12	INSTRUMENTATION	0.
13	RESEARCH EQUIPMENT	0.
14	INDIRECT VISION	0.
15	ENVIRONMENTAL	0.
16	ELECTRICAL	0.
17	INSTANT L/D PROP.	0.
18	LANDING GEAR	0.
19	EMERGENCY CHUTES	0.
20	CREW PROVISIONS	0.
21	DISPLAY PANEL	0.
22	ADAPTER STRUCTURE	0.
23	ADAPTER ENVIRONMENTAL	0.
24	ADAPTER ELECTRICAL	0.
25	ADAPTER DEORBIT PROP.	0.
26	ADAPTER MISCELLANEOUS	0.
27	INITIAL TOOLING	53483.
28	SUBSYSTEMS	53483.
29	STRUCTURE	53483.
30	HEAT SHIELD	0.
31	SURFACE CONTROL	0.
32	REACTION CONTROL	0.
33	GUID. & COMMUNICATION	0.
34	INSTRUMENTATION	0.
35	RESEARCH EQUIPMENT	0.
36	INDIRECT VISION	0.
37	ENVIRONMENTAL	0.
38	ELECTRICAL	0.
39	INSTANT L/D PROP.	0.
40	LANDING GEAR	0.
41	EMERGENCY CHUTES	0.
42	CREW PROVISIONS	0.
43	DISPLAY PANEL	0.
44	ADAPTER STRUCTURE	0.
45	ADAPTER ENVIRONMENTAL	0.
46	ADAPTER ELECTRICAL	0.
47	ADAPTER DEORBIT PROP.	0.
48	ADAPTER MISCELLANEOUS	0.
49	ASSEMBLY	0.
50	ACCEPTANCE TEST	0.
51	TOOL MAINTENANCE	8022.
52	INITIAL A.G.E.	0.
53	MANUFACTURING SITE	0.
54	HANDLING EQUIPMENT	0.
55	STRUCTURE SERVICE	0.
56	ELECTRONICS SERVICE	0.
57	MECHANICAL SERVICE	0.
58	ELECTRICAL SERVICE	0.
59	PROPULSION SERVICE	0.
60	ENVIRONMENTAL SERVICE	0.
61	VERIFICATION SYSTEM	0.
62	INSTRUMENTATION	0.
63	SIMULATORS	0.
64	MISSION EQUIPMENT	0.
65	DROP TEST AREA	0.
66	HANDLING EQUIPMENT	0.
67	STRUCTURE SERVICE	0.
68	ELECTRONICS SERVICE	0.
69	MECHANICAL SERVICE	0.
70	ELECTRICAL SERVICE	0.
71	PROPULSION SERVICE	0.
72	ENVIRONMENTAL SERVICE	0.
73	VERIFICATION SYSTEM	0.
74	INSTRUMENTATION	0.
75	SIMULATORS	0.
76	MISSION EQUIPMENT	0.
77	CAPTIVE FIRING SITE	0.
78	HANDLING EQUIPMENT	0.
79	STRUCTURE SERVICE	0.
80	ELECTRONICS SERVICE	0.
81	MECHANICAL SERVICE	0.
82	ELECTRICAL SERVICE	0.
83	PROPULSION SERVICE	0.
84	ENVIRONMENTAL SERVICE	0.
85	VERIFICATION SYSTEM	0.
86	INSTRUMENTATION	0.
87	SIMULATORS	0.
88	MISSION EQUIPMENT	0.
89	LAUNCH AREA	0.
90	HANDLING EQUIPMENT	0.
91	STRUCTURE SERVICE	0.
92	ELECTRONICS SERVICE	0.
93	MECHANICAL SERVICE	0.
94	ELECTRICAL SERVICE	0.
95	PROPULSION SERVICE	0.
96	ENVIRONMENTAL SERVICE	0.
97	VERIFICATION SYSTEM	0.
98	INSTRUMENTATION	0.
99	SIMULATORS	0.
100	MISSION EQUIPMENT	0.
101	RECOVERY AREA	0.
102	HANDLING EQUIPMENT	0.
103	STRUCTURE SERVICE	0.
104	ELECTRONICS SERVICE	0.
105	MECHANICAL SERVICE	0.
106	ELECTRICAL SERVICE	0.
107	PROPULSION SERVICE	0.
108	ENVIRONMENTAL SERVICE	0.
109	VERIFICATION SYSTEM	0.
110	INSTRUMENTATION	0.
111	SIMULATORS	0.
112	MISSION EQUIPMENT	0.
113	REFURBISHMENT SITE	0.
114	HANDLING EQUIPMENT	0.
115	STRUCTURE SERVICE	0.
116	ELECTRONICS SERVICE	0.
117	MECHANICAL SERVICE	0.
118	ELECTRICAL SERVICE	0.
119	PROPULSION SERVICE	0.
120	ENVIRONMENTAL SERVICE	0.
121	VERIFICATION SYSTEM	0.

TABLE 32.--Continued

HL-10 D/3 MODIFICATION FOR RENDEZVOUS AND DOCKING

122	INSTRUMENTATION	0.
123	SIMULATORS	0.
124	MISSION EQUIPMENT	0.
125	A.G.E. MAINTENANCE	0.
126	GROUND TESTING	34121.
127	STATIC TESTS	0.
128	PROPULSION TESTS	0.
129	INTEGRATED SYSTEM TESTS	0.
130	TEST ARTICLES	34121.
131	STRUCTURE	34121.
132	HEAT SHIELD	0.
133	SURFACE CONTROL	0.
134	REACTION CONTROL	0.
135	GUID. & COMMUNICATION	0.
136	INSTRUMENTATION	0.
137	RESEARCH EQUIPMENT	0.
138	INDIRECT VISION	0.
139	ENVIRONMENTAL	0.
140	ELECTRICAL	0.
141	INSTANT L/D PROP.	0.
142	LANDING GEAR	0.
143	EMERGENCY CHUTES	0.
144	CREW PROVISIONS	0.
145	DISPLAY PANEL	0.
146	ADAPTER STRUCTURE	0.
147	ADAPTER ENVIRONMENTAL	0.
148	ADAPTER ELECTRICAL	0.
149	ADAPTER DEORBIT PROP.	0.
150	ADAPTER MISCELLANEOUS	0.
151	ASSEMBLY	0.
152	ACCEPTANCE TEST	0.
153	SPACECRAFT SPARES	5118.
154	FLIGHT TESTING	0.
155	AIR DROP FLIGHTS	0.
156	RECOVERY DROP	0.
157	PAD & MAX-Q ABORT	0.
158	UNMANNED ORBITAL	0.
159	MANNED ORBITAL	0.
160	TEST ARTICLES	0.
161	STRUCTURE	0.
162	HEAT SHIELD	0.
163	SURFACE CONTROL	0.
164	REACTION CONTROL	0.
165	GUID. & COMMUNICATION	0.
166	INSTRUMENTATION	0.
167	RESEARCH EQUIPMENT	0.
168	INDIRECT VISION	0.
169	ENVIRONMENTAL	0.
170	ELECTRICAL	0.
171	INSTANT L/D PROP.	0.
172	LANDING GEAR	0.
173	EMERGENCY CHUTES	0.
174	CREW PROVISIONS	0.
175	DISPLAY PANEL	0.
176	ADAPTER STRUCTURE	0.
177	ADAPTER ENVIRONMENTAL	0.
178	ADAPTER ELECTRICAL	0.
179	ADAPTER DEORBIT PROP.	0.
180	ADAPTER MISCELLANEOUS	0.
181	ASSEMBLY	0.
182	ACCEPTANCE TEST	0.
183	SPACECRAFT TRANSPORTING	0.
184	LAUNCH VEHICLES	0.
185	ADAPTATION	0.
186	LITTLE JOE II	0.
187	TITAN III 2 SEG WO/TS	0.
188	TITAN III 2 SEG W/TS	0.
189	TITAN III 5 SEG WO/TS	0.
190	TITAN III 5 SEG W/TS	0.
191	MISSION SUPPORT	0.
192	INITIAL TRAINING	0.
193	INITIAL TRAINING EQUIP.	0.
194	NONRECURRING (FACILITIES)	0.
195	INSTALLATION (INITIAL)	0.
196	SPACECRAFT	0.
197	MANUFACTURING SITE	0.
198	DROP TEST AREA	0.
199	CAPTIVE FIRING SITE	0.
200	LAUNCH AREA	0.
201	RECOVERY AREA	0.
202	REFURBISHMENT SITE	0.
203	MISSION CONTROL	0.
204	CENTRAL CONTROL	0.
205	LAND RANGE STATIONS	0.
206	SEA RANGE STATIONS	0.
207	MAINTENANCE	0.
208	SPACECRAFT	0.
209	MANUFACTURING SITE	0.
210	DROP TEST AREA	0.
211	CAPTIVE FIRING SITE	0.
212	LAUNCH AREA	0.
213	RECOVERY AREA	0.
214	REFURBISHMENT SITE	0.
215	MISSION CONTROL	0.
216	CENTRAL CONTROL	0.
217	LAND RANGE STATIONS	0.
218	SEA RANGE STATIONS	0.
	CUMULATIVE TOTAL COST	298904.

F I S C A L   F U N D I N G

	YEAR	S/C CONTRACT	L/V COSTS	OTHER	TOTALS
1	1971	143433.	0.	3410.	146843.
2	1972	141237.	0.	10823.	152060.

C U M U L A T I V E   F U N D S

	YEAR	S/C CONTRACT	L/V COSTS	OTHER	TOTALS
1	1971	143433.	0.	3410.	146843.
2	1972	284671.	0.	14233.	298904.

TABLE 32. --Continued

HL-10 D/3 MODIFICATION FOR RENDEZVOUS AND DOCKING

		YEAR 1972
1	RECURRING (OPERATIONAL)	32926508.
2	MANAGEMENT	1863764.
3	SUSTAINING ENGINEERING	36785.
4	SPACECRAFT	1133777.
5	PROCUREMENT	0.
6	STRUCTURE	0.
7	HEAT SHIELD	0.
8	SURFACE CONTROL	0.
9	REACTION CONTROL	0.
10	GUID. & COMMUNICATION	0.
11	INSTRUMENTATION	0.
12	RESEARCH EQUIPMENT	0.
13	INDIRECT VISION	0.
14	ENVIRONMENTAL	0.
15	ELECTRICAL	0.
16	INSTANT L/D PROP.	0.
17	LANDING GEAR	0.
18	EMERGENCY CHUTES	0.
19	CREW PROVISIONS	0.
20	DISPLAY PANEL	0.
21	ADAPTER STRUCTURE	0.
22	ADAPTER ENVIRONMENTAL	0.
23	ADAPTER ELECTRICAL	0.
24	ADAPTER DEORBIT PROP.	0.
25	ADAPTER MISCELLANEOUS	0.
26	ASSEMBLY	0.
27	ACCEPTANCE TEST	0.
28	TRANSPORTATION	1104.
29	SPARES	1132672.
30	ADDITIONAL TOOLING	0.
31	TOOL MAINTENANCE	1332.
32	ADDITIONAL A.G.E.	0.
33	MANUFACTURING SITE	0.
34	DROP TEST AREA	0.
35	CAPTIVE FIRING SITE	0.
36	LAUNCH AREA	0.
37	RECOVERY AREA	0.
38	REFURBISHMENT SITE	0.
39	A.G.E. MAINTENANCE	0.
40	DROP TEST OPERATIONS	0.
41	CAPTIVE FIRING OPERATIONS	0.
42	LAUNCH OPERATIONS	2022219.
43	RECOVERY OPERATIONS	1213331.
44	REFURBISHMENT OPERATIONS	4530690.
45	STRUCTURE	20610.
46	HEAT SHIELD	1406955.
47	SURFACE CONTROL	30138.
48	REACTION CONTROL	10532.
49	GUID. & COMMUNICATION	48873.
50	INSTRUMENTATION	25561.
51	RESEARCH EQUIPMENT	0.
52	INDIRECT VISION	0.
53	ENVIRONMENTAL	7300.
54	ELECTRICAL	17718.
55	INSTANT L/D PROP.	51996.
56	LANDING GEAR	8631.
57	EMERGENCY CHUTES	322572.
58	CREW PROVISIONS	0.
59	DISPLAY PANEL	1125.

		Year 1972
60	ADAPTER STRUCTURE	375631.
61	ADAPTER ENVIRONMENTAL	0.
62	ADAPTER ELECTRICAL	0.
63	ADAPTER DEORBIT PROP.	151070.
64	ADAPTER MISCELLANEOUS	389252.
65	ASSEMBLY	506955.
66	ACCEPTANCE TEST	1155765.
67	MISSION CONTROL OPERATIONS	2885818.
68	LAUNCH VEHICLES	19238796.
69	LITTLE JOE II	0.
70	TITAN III 2 SEG WO/TS	0.
71	TITAN III 2 SEG W/TS	0.
72	TITAN III 5 SEG WO/TS	19238796.
73	TITAN III 5 SEG W/TS	0.
74	TRAINING OPERATIONS	0.
75	ADDITIONAL TRAINING EQUIP.	0.
76	RECURRING (FACILITIES)	340048.
77	INSTALLATION (OPS. ADDIT.)	0.
78	SPACECRAFT	0.
79	MANUFACTURING SITE	0.
80	DROP TEST AREA	0.
81	CAPTIVE FIRING SITE	0.
82	LAUNCH AREA	0.
83	RECOVERY AREA	0.
84	REFURBISHMENT SITE	0.
85	MISSION CONTROL	0.
86	CENTRAL CONTROL	0.
87	LAND RANGE STATIONS	0.
88	SEA RANGE STATIONS	0.
89	MAINTENANCE	340048.
90	SPACECRAFT	208450.
91	MANUFACTURING SITE	83634.
92	DROP TEST AREA	0.
93	CAPTIVE FIRING SITE	0.
94	LAUNCH AREA	842[illegible]4.
95	RECOVERY AREA	40610.
96	REFURBISHMENT SITE	0.
97	MISSION CONTROL	131597.
98	CENTRAL CONTROL	26319.
99	LAND RANGE STATIONS	65798.
100	SEA RANGE STATIONS	39479.
	CUMULATIVE TOTAL COST	33565464.

TABLE 32. --Concluded

HL-10 D/3 MODIFICATION FOR RENDEZVOUS AND DOCKING

OPERATIONAL COSTS SUMMARY

101	RECURRING (OPERATIONAL)	32926508.
102	MANAGEMENT	1863764.
103	SUSTAINING ENGINEERING	36785.
104	SPACECRAFT	1133777.
105	PROCUREMENT	0.
106	STRUCTURE	0.
107	HEAT SHIELD	0.
108	SURFACE CONTROL	0.
109	REACTION CONTROL	0.
110	GUID. & COMMUNICATION	0.
111	INSTRUMENTATION	0.
112	RESEARCH EQUIPMENT	0.
113	INDIRECT VISION	0.
114	ENVIRONMENTAL	0.
115	ELECTRICAL	0.
116	INSTANT L/D PROP.	0.
117	LANDING GEAR	0.
118	EMERGENCY CHUTES	0.
119	CREW PROVISIONS	0.
120	DISPLAY PANEL	0.
121	ADAPTER STRUCTURE	0.
122	ADAPTER ENVIRONMENTAL	0.
123	ADAPTER ELECTRICAL	0.
124	ADAPTER DEORBIT PROP.	0.
125	ADAPTER MISCELLANEOUS	0.
126	ASSEMBLY	0.
127	ACCEPTANCE TEST	0.
128	TRANSPORTATION	1104.
129	SPARES	1132672.
130	ADDITIONAL TOOLING	0.
131	TOOL MAINTENANCE	1332.
132	ADDITIONAL A.G.E.	0.
133	MANUFACTURING SITE	0.
134	DROP TEST AREA	0.
135	CAPTIVE FIRING SITE	0.
136	LAUNCH AREA	0.
137	RECOVERY AREA	0.
138	REFURBISHMENT SITE	0.
139	A.G.E. MAINTENANCE	0.
140	DROP TEST OPERATIONS	0.
141	CAPTIVE FIRING OPERATIONS	0.
142	LAUNCH OPERATIONS	2022219.
143	RECOVERY OPERATIONS	1213331.
144	REFURBISHMENT OPERATIONS	4530690.
145	STRUCTURE	20610.
146	HEAT SHIELD	1406955.
147	SURFACE CONTROL	30138.
148	REACTION CONTROL	10532.
149	GUID. & COMMUNICATION	48873.
150	INSTRUMENTATION	25561.
151	RESEARCH EQUIPMENT	0.
152	INDIRECT VISION	0.
153	ENVIRONMENTAL	7300.
154	ELECTRICAL	17718.
155	INSTANT L/D PROP.	51996.
156	LANDING GEAR	8631.
157	EMERGENCY CHUTES	322572.
158	CREW PROVISIONS	0.
159	DISPLAY PANEL	1125.
160	ADAPTER STRUCTURE	375631.
161	ADAPTER ENVIRONMENTAL	0.
162	ADAPTER ELECTRICAL	0.
163	ADAPTER DEORBIT PROP.	151070.
164	ADAPTER MISCELLANEOUS	389252.
165	ASSEMBLY	506955.
166	ACCEPTANCE TEST	1155765.
167	MISSION CONTROL OPERATIONS	2885818.
168	LAUNCH VEHICLES	19238796.
169	LITTLE JOE II	0.
170	TITAN III 2 SEG WO/TS	0.
171	TITAN III 2 SEG W/TS	0.
172	TITAN III 5 SEG WO/TS	19238796.
173	TITAN III 5 SEG W/TS	0.
174	TRAINING OPERATIONS	0.
175	ADDITIONAL TRAINING EQUIP.	0.
176	RECURRING (FACILITIES)	340048.
177	INSTALLATION (OPS. ADDIT.)	0.
178	SPACECRAFT	0.
179	MANUFACTURING SITE	0.
180	DROP TEST AREA	0.
181	CAPTIVE FIRING SITE	0.
182	LAUNCH AREA	0.
183	RECOVERY AREA	0.
184	REFURBISHMENT SITE	0.
185	MISSION CONTROL	0.
186	CENTRAL CONTROL	0.
187	LAND RANGE STATIONS	0.
188	SEA RANGE STATIONS	0.
189	MAINTENANCE	340048.
190	SPACECRAFT	208450.
191	MANUFACTURING SITE	83634.
192	DROP TEST AREA	0.
193	CAPTIVE FIRING SITE	0.
194	LAUNCH AREA	84204.
195	RECOVERY AREA	40610.
196	REFURBISHMENT SITE	0.
197	MISSION CONTROL	131597.
198	CENTRAL CONTROL	26319.
199	LAND RANGE STATIONS	65798.
200	SEA RANGE STATIONS	39479.
	TOTAL OPERATIONAL COST	33266556.