CR-66353

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

FINAL REPORT

Part II. Research Program Experiments

May 1967

Prepared Under Contract No. NAS 1-6209 by
MARTIN MARIETTA CORPORATION
Baltimore, Maryland 21203
for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PRECEDING PAGE BLANK NOT FILMED.

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:

I.	Summary	CR-66352
II.	Research Program Experiments	CR-66353
III.	Flight Performance	CR-66354
IV.	Candidate Entry Vehicle Designs	CR-66355
V.	Systems Integration	CR-66356
VI.	Research Vehicle Size Selection and Program Definition	CR-66357
VII.	Selected Entry Vehicle Design	CR-66358
VIII.	Alternative Approaches	CR-66359

The study was managed at Martin Marietta by:

Robert L. Lohman--Study Manager

Rudolph C. Haefeli--Assistant Study Manager

The principal contributors to the study were James McCown, Robert Schwab, Ray Sorrell and James Vaeth; Mr. Louis Sheldahl also made a major contribution to the study as Study Manager during the first quarter.

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.

CONTENTS

Page

SUMMARY

This Part of the final report of the "Study of the Influence of Size of a Manned Lifting Body Entry Vehicle on Research Potential and Cost" presents the identification, justification and value of experiments to be included in the entry research program. The results of this phase of the study served as the model of the entry research which was used as a basis for design of the entry vehicles and in cost and effectiveness studies.

The scope of this Part of the study was limited to analysis of research requirements for earth entry of a medium L/D lifting body entry vehicle, specifically the HL-10, returning from near-earth missions. As secondary objectives, research applicable to rendezvous and docking of lifting body entry vehicles and research of supercircular velocity entry were to be investigated. All other spaceflight research such as zero-g effects on pilot, scientific studies of weather, etc., was specifically excluded.

To aid in the identification and definition of entry research, eight potential operational missions were identified. These missions included operations such as space-station logistics, space reconnaissance, satellite inspection, space rescue, lunar return, and planetary return. The flight requirements that each of these missions impose on an entry vehicle were estimated. The entry conditions for the near-earth missions were shown to have a large degree of commonality. These entry requirements were then compared with current state-of-the-art capabilities, and deficiencies were revealed which thereby identified potential requirements for research. In addition, other research tasks were identified to fulfill specific program objectives such as making possible (1) the elimination of the prototype step when developing an operational manned lifting body entry vehicle and (2) advances in state of the art for lifting entry.

These considerations resulted in the identification of 52 specific entry research tasks. Each of these tasks was defined in detail, including its objective, a description of how it was to be conducted, the number and type of entry conditions to be flown and number and type of measurements to be made, and an assessment of the crew time and the equipment weight required for performance of the task.

In addition, a numerical value of their inherent worth, called the intrinsic value, was established for each task using the Law of Comparative Judgment. This is a method developed by L. L. Thurstone which establishes the positions of things, having no physically measurable attribute, on a numerical scale. Using this technique, a scale for the intrinsic value of the 52 research tasks was developed having tasks spaced from the lowest at a value of unity, FM-19 "Synergetic Maneuver Simulation Without Thrust," to the highest at a value of 237.1, SM-1, "Ablative Heat Shield Performance and Analysis Correlation." Modifications to this value scale to account for reliability and flight programming are discussed in Part VI.

Another important result of this study phase was the establishment of the research program entry flight spectrum. Eleven specific entry conditions were selected within this flight spectrum to cover all the research requirements. These ranged from nominal flights to the center of the landing footprint to flights with more severe environments and systems requirements using crossrange maneuvers. Special entry conditions were also included for high altitude abort (an unmanned heat shield qualifying flight), for supercircular velocity entry flight, and for a synergetic maneuvering flight.

I. INTRODUCTION

This Part of the final report on a "Study of the Influence of Size of a Manned Lifting Body Vehicle on Research Potential and Project Cost," presents the research tasks identified for this study, including the requirements which these experiments impose on the entry vehicle and its crew, and including an analysis of the value of each task.

At the beginning of this study, an attempt was made to relate requirements for entry research to specific postulated operational missions. Accordingly, an identification and definition logic was established that had this as the major objective. It soon became apparent, however, that for the missions of primary interest (i.e., near-earth), the requirement for entry research was nearly independent of the mission since all those considered had equal, or nearly equal, requirements. As discussed in Section II of this report, this development necessitated a modification of the identification and definition logic initially proposed.

A necessary adjunct to the task of identifying research tasks was an effort to define the entry flight condition spectrum of interest. In accordance with provisions of the contract Statement of Work this was done primarily for near-earth entry but also considered supercircular-velocity entry. The parametric studies leading to the selection of a specific spectrum are presented in Part III, whereas, the operational considerations that had an influence in this selection are discussed in Part V. The resulting spectrum and specific entry condition in this spectrum selected for study are discussed in Section III of this Part of the final report.

Fifty-two research tasks were identified, defined in some detail, and in accordance with the provisions of the contract Statement of Work, submitted to the NASA for review and approval. Thus, the research tasks included in this report constitute the list of NASA approved research tasks that served as the model of potential entry research for the cost and effectiveness analysis performed as part of the above named study. The detail definition and justification for each of these 52 research tasks are presented in Section IV.

In the cost and effectiveness analysis, a technique was developed for assigning the research tasks to flights of a specified flight plan. In order to do this, it was necessary to establish the requirements of each research task such as weight of the equipment required, number of crewmen, and type and number of entry conditions to be flown. This type of data, although included in the detail description of each task presented in Section IV, is repeated in summary form in Section V for ready reference.

Another special requirement of the cost and effectiveness analysis was the need for establishing an intrinsic value for each research task. Section VI is a detailed discussion of the techniques and results of this value analysis. Since intrinsic value of research tasks was not a physically measurable attribute, measuring techniques that do not require a physically measurable attribute were investigated. One, the Law of Comparative Judgment was selected, and from application of this law, a value scale for all 52 research tasks was developed.

An important function of the research tasks defined herein, beyond the model for potential research in the cost and effectiveness analysis, is that they support justification for a manned flight research program. As discussed in Section VI of this report, one of the primary goals of defining potential entry research was to determine if there were requirements for research, and if it was worthwhile enough to justify the conduct of a manned lifting body research program.

During the effort to define research tasks, several were identified that must be performed before any manned orbital lifting body entry vehicle could be classed as operational, but they did not qualify as research tasks. These were identified as basic flight test tasks and are included in Section V.

II. IDENTIFICATION AND DEFINITION LOGIC

A. GENERAL DESCRIPTION

Figure 1 shows the logic employed for identifying and defining the research tasks. The number in each block of this diagram indicates the sequence in which the various steps of the exercise were performed.

Steps 1 through 5* were performed to identify research tasks while steps 6 through 10 were performed to define the requirements for them. However, during the definition phase of this effort, as shown on the logic diagram, if none of the available instruments were capable of meeting the performance specification established in step 7, this would define a requirement for a new instrument and in all probability would lead to the identification of another research task. As a matter of fact, research task SM-13 was identified in this way.

Although the logic diagram shows a clear sequence of steps in the analysis, it should be recognized that a certain amount of iteration took place during this effort and is discussed in more detail below.

B. RESEARCH TASK IDENTIFICATION

Mission Analysis (Step 1*)

The first step in the effort to identify research tasks was an analysis of the potential operational missions for a manned lifting body entry vehicle. Figure 2 shows the scope of this task. Three classes of application, and eight distinct missions were included in this analysis. All possible mission phases were included, but not all areas of interest were identified for each phase since some phases are specifically excluded from the scope of this analysis by the provisions of the contract SOW. As shown in figure 2, mission phase areas of interest are designated primary or secondary, also in accordance with the contract SOW.

Mission concept specifications were prepared for all eight missions considered. The preparation of these specifications established general information from which the mission requirements could be extracted. Table 1 is a summary of the pertinent characteristics of each mission studied. Table 2 is a summary of mission vehicle requirement data.

The data of table 1 reveals what might be a surprising consistency in the entry conditions required for the various low earth missions. However, this is simply a reflection of the fact that the only mission parameter that significantly influences the entry conditions is the return time. Since the return time requirement is, for all practical purposes, the same for all near earth missions considered, the entry performance requirements for these missions are also the

* Step numbers correspond to the block numbers on Figure 1.

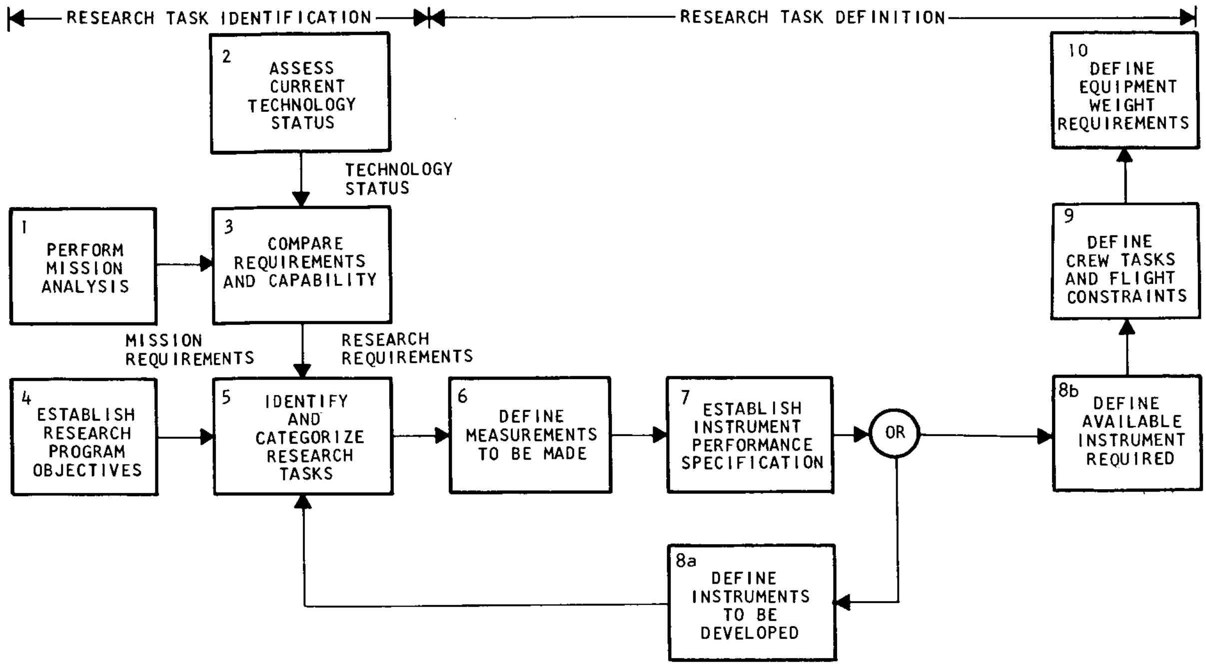


FIGURE 1. RESEARCH TASK IDENTIFICATION AND DEFINITION LOGIC

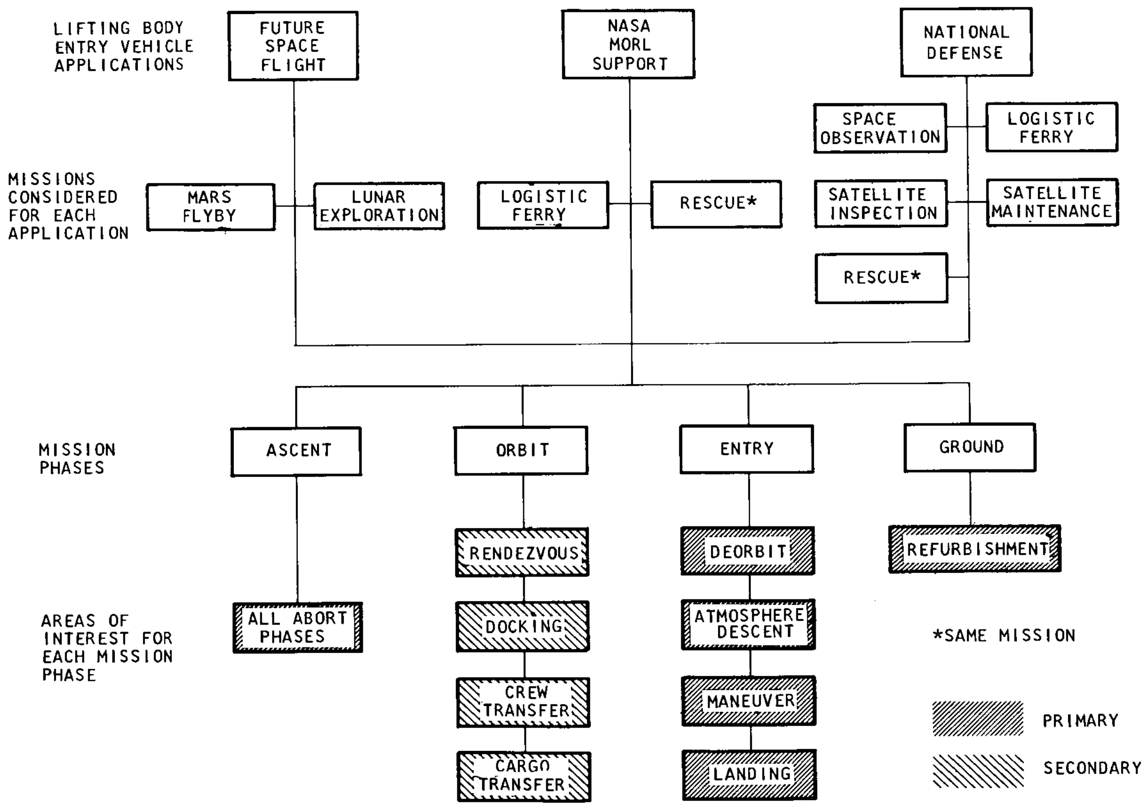


FIGURE 2. MISSION ANALYSIS SCOPE

TABLE 1

SUMMARY OF MISSION CHARACTERISTICS

Mission ↓ / Parameter →	Orbit definition: Altitude, h, naut mi	Orbit definition: Inclination, i, deg	Minimum return time, hr	Entry conditions at 400 000 ft (122 km): Velocity, V, fps	Entry conditions at 400 000 ft (122 km): Flight path angle, γ, deg	Performance required: ΔV, fps	Performance required: Crossrange, naut mi	Acceleration, g
MOL support	80 to 200 (148.2 to 370 km)	80 to 100	4 to >12	25 000 to 25 600 (7.62 to 780.3 km/sec)	-1 to -3	1 700 (.518 km/sec)	500 (926 km)	1 to 3
MORL support	164 (308 km)	50	4 to >12	25 300 to 25 800 (7.711 to 7.864 km/sec)	-1 to -3	1 700 (.518 km/sec)	160 (296 km)	1 to 4
Satellite inspection	80 to 500 (148.2 to 926 km)	55 to 100	2 to >12	25 000 to 26 200 (7.62 to 7.986 km/sec)	-1 to -3	3 000 (.914 km/sec)	1700 (3148 km)	1 to 6
Space observation	70 to 108 (130 to 200. km)	25 to 96.5	2 to >12	24 200 to 25 600 (7.376 to 780.3 km/sec)	-1 to -3	2 500 (.762 km/sec)	1700 (3148 km)	1 to 3
Search and rescue	70 to 500 (130 to 926. km)	25 to 100	4 to >12	25 000 to 26 500 (7.62 to 8.08 km/sec)	-1 to -3	4 000 (1.219 km/sec)	2000 (3704 km)	1 to 6
Satellite repair and maintenance	100 to 20 000 (185 km to 37 Mm)	25 to 100	≥12	25 000 to 35 000 (7.62 to 10.67 km/sec)	-1 to -5	10 000 (3.048 km/sec)	100 (185.2 km)	1 to 5
Lunar logistics	Escape	0 to 30	NA	34 000 to 40 000 (10.36 to 12.19 km/sec)	-5 to -12	0-1 000 (.305 km/sec)	100 (185.2 km)	2 to 10
Mars flyby	Escape	0 to 30	NA	38 000 to 73 000 (11.58 to 22.25 km/sec)	-6 to -11	0-1 000 (.350 km/sec)	100 (185.2 km)	2 to 10

Mission ↓ / Parameter →	Entry environment: Heat rate, $\dot{q}$, Btu/ft^2-sec	Entry environment: Total heat, Q, Btu/ft^2	Entry environment: Dynamic pressure, q, lb/ft^2	Communication: Required flight times	Communication: Types: Voice	Communication: Types: Picture	Communication: Types: Data	Navigation: Deorbit precision	Navigation: Inertial navigation system
MOL support	80 to 270 (908 to 3064. kW/m^2)	70 to 150 x 10^{-3} (794. to 1702. MJ/m^2)	350 to 400 (16.8 to 19.2 kN/m^2)	All times except blackout	✓			✓	✓
MORL support	80 to 270 (908 to 3064. kW/m^2)	70 to 150 (794. to 1702. MJ/m^2)	350 to 400 (16.8 to 19.2 kN/m^2)	All times except blackout	✓			✓	✓
Satellite inspection	80 to 270 (908 to 3064. kW/m^2)	70 to 150 (794. to 1702. MJ/m^2)	350 to 400 (16.8 to 19.2 kN/m^2)	All times	✓	✓	✓	✓	✓
Space observation	70 to 270 (794.4 to 3064. kW/m^2)	60 to 150 (681. to 1702. MJ/m^2)	350 to 400 (16.8 to 19.2 kN/m^2)	All times	✓	✓	✓	✓	✓
Search and rescue	70 to 300 (794.4 to 3405. kW/m^2)	70 to 170 (794. to 1929. MJ/m^2)	350 to 400 (16.8 to 19.2 kN/m^2)	All times except blackout	✓			✓	✓
Satellite repair and maintenance	80 to 380 (908 to 4313. kW/m^2)	70 to 200 (794. to 2270. MJ/m^2)	400 to 600 (19.2 to 28.7 kN/m^2)	↓	✓			✓	✓
Lunar logistics	1000 to 3000 (11 350. to 34 047. kW/m^2)	70 to 220 (794. to 2497. MJ/m^2)	400 to 800 (19.2 to 38.3 kN/m^2)	↓	✓			Entry precision	✓
Mars flyby	2000 to 1000 (22 698. to 11 350. kW/m^2)	70 to 9000 (794. to 102 140. MJ/m^2)	500 to 1500 (23.9 to 71.8 kN/m^2)	↓	✓			↓	✓

TABLE 2

SUMMARY OF MISSION REQUIREMENTS

Mission	Crew size	Occupancy time, days	On-orbit time, days	Rendezvous and docking required	Reuse required	Runway length ft	Runway length (km)	Recovery site or sites	Volume required (internal) ft^3	Volume required (internal) (m^3)	Weight required (internal) lb	Weight required (internal) (Mg)
Logistic support												
MOL	2	6	30 to 90	Yes	Yes	10 000	(3.05)		357	(10.1)	5 064	(2.297)
MORL	6	6	30 to 90	Yes	↕	10 000	(3.05)					
Satellite inspection	2	3	3	Rendezvous only	↕	6 000	(1.83)	Edwards AFB	129.2	(3.66)	3 095	(1.404)
Space observation	2	0.5 to 7	0.5 to 7	No	↕	6 000	(1.83)	Edwards AFB	483.6	(13.69)	11 586	(5.255)
Rescue	7	2	2	Yes	↕	5 000	(1.52)	Edwards AFB	313.5	(8.88)	4 209	(1.905)
Satellite repair and maintenance	2	7	7	Yes	↕	10 000	(3.05)		292	(8.27)	4 664	(2.116)
Lunar	3	14	14	No	↕	10 000	(3.05)					
Mars	4	180	180	Yes		10 000	(3.05)					

same. Numerous mission studies, particularly of DOD missions, have attempted to find a justification for return times less than four hours but have failed to do so convincingly.

Assess Current Technology Status (Step 2)

The second step of the effort to identify research tasks was to assess the current status of lifting body entry vehicle technology. In general, this assessment provides the following conclusions:

(a) Medium L/D technology is well in hand (i.e., a successful manned flight vehicle could be built using present technology).

(b) Operating procedures (such as refurbishment turnaround maintenance, standby readiness) are not well defined.

(c) Flying techniques and handling qualities are not well known.

(d) Man-machine interface is not well known.

(e) Analytical techniques for aerodynamic phenomena prediction are not confirmed in real environment.

(f) Heat shield technology for other than ablative type is not well developed.

(g) Subsystems technology is well in hand.

(h) Current communication technology is well in hand except communications through blackout environment.

Compare Requirements and Capability (Step 3)

The purpose of this step in the analysis was to show those areas where the current technology capability could not meet the mission requirements in order to identify fruitful areas for research.

In assessing the requirements of table 1 and considering the results of other studies (refs. 1, 2, 3), it seems clear that all the missions studied can be accomplished at medium L/D. The crossranges noted are, in some cases, beyond the aerodynamic capability of medium L/D vehicles, and this, of course, suggests an area of research related to higher performance vehicles. However, detailed tradeoff studies (refs. 2 and 3, for instance) have indicated that the medium L/D vehicle with the use of some on-orbit propulsion for these higher crossranges is optimum on a cost-effectiveness basis.

If we accept that all missions can, in fact, be accomplished at medium L/D, then the entry environment, the guidance, navigation and communications problems are all generally within the technology represented by PRIME and by the baseline research vehicle designs, i.e., by present technology.

The predominant effect of the Lunar and Mars Flyby missions is to introduce higher entry velocities, affecting primarily the heat shield design and the navigation and guidance areas. Probably the most difficult questions in regard to research relative to Lunar, but especially Mars return, are: How do we fly such a research mission? On what booster? How do we get the entry velocity and what does it cost? These questions are, of course, a specific part of the secondary objectives.

With regard to the research that might be required to explore problems posed by a lifting vehicle in rendezvous, docking, crew transfer, etc., past studies have indicated very little need for research (as distinct from development) and this is reflected in research tasks defined to date. Because of its secondary role in the study, it has, however, received less attention than the entry phase and is subject to further evaluation.

With this general picture--the conclusions that medium L/D lifting bodies (and subsystems) are generally adequate for the primary missions, and the fact that, as stated above, the medium L/D lifting body technology is well in hand--little or no areas for research exist insofar as filling technology gaps are concerned. This fact leads to the need for an addition to the methodology employed in identifying research tasks as discussed in the next section.

Establish Research Program Objectives (Step 4)

The purpose of this step in the analysis was to furnish an additional means for identifying research tasks since the direct comparison between the mission requirements and the current technology status produced few research tasks. The objectives finally agreed upon are:

(a) Make possible the elimination of the prototype step when developing a manned operational mission vehicle of medium L/D class for:

   (1) All the near-earth missions listed in figure 2 where the operational altitude is limited to 500 nautical miles (926 km), entry velocities of near 25 000 fps (7.62 km/sec) but not to exceed 30 000 fps (9.14 km/sec), and entry angles not to exceed -3°.

   (2) All the earth synchronous missions listed in figure 2 (satellite maintenance and repair) where entry velocities are between 30 000 and 35 000 fps (9.14 and 10.7 km/sec) and entry angles between -5° and -12°.

(b) Advance the state of the art in the area of lifting entry as applied to any of the missions listed in figure 2.

(c) Advance the state of the art in areas of hypersonic flight, plasma physics, etc., where the motivation is primarily scientific rather than applied to known mission objectives.

(d) Provide support to other (than manned) entry missions, such as warhead entry, decoy discrimination, reduction of signature as applied to penetration and so forth (not presently in scope, thus, no further consideration was given to this objective at this time).

The technical specialists charged with identifying research tasks were directed to define research tasks that would enable the research program to meet the objectives stated.

Identify and Categorize Research Tasks (Step 5)

The final step in the effort to identify research tasks was the actual compiling of a list of research tasks, describing them in some detail and categorizing them by some classification scheme. For this task, three different forms were utilized. First, there is a Research Task Justification form; second, there is a Research Task Definition form; and, finally, there is a Research Task Summary form.

The Research Task Justification form contains the title and number of the task, then a discussion of the technology assessment task, the capability and requirement comparison, and what research program objective is met or supported, all under the title of "Technology Status Assessment." Next, under the title of "Justification for Test on Research Vehicle" is a discussion of why a flight research vehicle is required as opposed to ground testing or analytical analysis. Finally, this form contains a discussion of man's contribution to the research task under the title "Crew Tasks During Experiment."

The Research Task Definition form contains the task title and number, a discussion of the objective of the task and a detailed description of what will be done during the task and how the task will be performed. The rest of this form contains information generated during the Research Task Definition effort and will be discussed later herein.

The Research Task Summary form summarizes, for each research task, the mission and mission phase to which the task applied, the research task category, the role of man in the task and a statement as to whether the task supports a primary or secondary objective as defined in the SOW.

Describing the tasks once identified was no problem, but the identification, categorization and the justification proved to be difficult. Categorization is an important consideration since it is an aid to research-program planning, research task identification and management and measurement of value. Since even a small number of tasks could be categorized in many ways, this dilemma was quite difficult to resolve. The tasks identified in this report have been classified two ways. First, they have been grouped according to subsystem designation or technical discipline (i.e., heat shield, aero performance, etc.) and, second, they have been assigned groupings in accordance with the research program objective supported. Three titles have been developed for this latter grouping method that correspond to the three research program objectives previously discussed.

For the first objective (e.g., Eliminate Prototype for Low Earth Missions), all the research tasks are largely in the nature of design or analysis confirmation or operation procedures verification. Thus, the first category is called "Confirmation or Verification."

For the second objective (e.g., Advance the State of the Art for for Any Mission Considered), the research tasks are largely concerned with equipment or procedures, state-of-art-advances. Thus, the second category is called "Technology Advances."

The final objective (e.g., Scientific Knowledge Advances) encompasses those areas of research that are more nearly pure research as opposed to applied research, since there is no immediate mission application identified. Thus, the third research category is called "Pure Research."

C. RESEARCH TASK DEFINITION

In order to be able to determine the best flight loading plan for the research tasks identified, it is necessary to know more about these tasks than just identifying titles. As mentioned previously, steps 6 through 9 in the research task identification and definition effort were performed to generate this detailed data. The results of these steps are documented on the Research Task Definition forms and other tables included in this Part. A short discussion of each of the steps that produced these results follows.

Define Measurements to be Made (Step 6)

After a research task requirement had been identified and a discussion of the objective and a detailed description of the task to satisfy the requirement prepared (see previous discussion of Step 5), measurements necessary to support the task were identified. This step was an essential adjunct to the definition of the equipment required in support of the task. Measurements to be made are listed under the title "Parameter" on the Research Task Definition forms. As an example, for Task SM-2, Ablative Heat Shield Joints, parameters identified as requiring measurement were temperature, surface cracking and substrate panel strain.

Establish Instrument Performance Specification (Step 7)

The next step was to establish, for all research tasks, performance requirements for each of the measurement parameters identified in the preceding step. The resulting information is presented in the Appendix, and includes the frequency response and accuracy required for each specific measurement.

Define Instruments to be Developed (Step 8a)

After the required instrument performance was established, two alternative steps result because of the possibility that available equipment would not meet the performance specifications. The first alternative covers this case, and identifies and defines instrumentation which would need to be developed in order to accomplish the research tasks. The results of this step are then fed back into step 5 so that a research task for accomplishing the necessary development could be established. As a result of the requirements established for FM-12, Boundary Layer Survey, and FM-14, Viscous Effects on Lift and Drag, this feedback loop was used and resulted in Task SM-13, Heat Shield Instrumentation Studies.

Define Available Instrument Required (Step 8b)

The second alternative case following step 7 is that where available equipment could meet the instrument performance identified in that step. In this case, a simple matching of available instrumentation with the required performance specifications was performed. Results of this step are also presented in the Appendix.

Define Crew Tasks and Flight Constraints (Step 9)

This step could be performed concurrently with step 8b, since starting it is not dependent on the completion of step 8b. Also, it was possible to combine definition of crew tasks with definition of flight constraints since they are somewhat interrelated. The results of the crew task analysis are presented in table 11, and those of the constraint analysis are presented in table 12. A brief discussion of the effort performed is presented in Section V.

Define Equipment Weight Requirements (Step 10)

The final step in the analysis to define the research tasks was to identify the weight requirements for the hardware necessary for each task. Results of this step are presented on the Research Task Definition forms. It will be noted that instrumentation weight was excluded from the analysis because it was included in the entry vehicle weight, as explained in Section V.C. A summary of the weight requirements for each research task is included in table 11.

III. ENTRY RESEARCH FLIGHT SPECTRUM

An important part of the task to identify research tasks was the definition of the flight spectrum of interest for entry research. Detailed parametric flight performance studies (see Part III) and consideration of operational aspects (see Part V) resulted in the definition of the entry research flight spectrum. A typical landing footprint and corresponding entry environmental data are found in figure 3 to illustrate this spectrum and specific entry conditions. The data of this figure were generated from analog simulations of trajectories flown with an HL-10 entry vehicle entering at a velocity of 25 860 fps (7.88 km/sec) and an entry angle of -1.5°. These parametric data were based on using an angle of attack program for constant L/D and a constant bank angle throughout entry.

Once the spectrum of entry conditions shown in figure 3 had been established, the next step was to select a set of specific entry flight conditions that adequately cover all the required conditions for use in the research task assignment effort (i.e., cost and effectiveness analysis discussed in Part VI). Three major categories of conditions were selected, and these are discussed in detail below. The specific flight conditions for each category are defined in detail in table 3, and the pertinent detail performance data for each are shown in table 4. Constraints on the sequence of specifying entry conditions are discussed in Part VI.

A. UNMANNED

In an manned flight program, it is necessary to first fly some unmanned vehicles for verification of the safety of the flight systems. The specific entry conditions selected for the unmanned testing are entry conditions A and B. Entry condition B (fig. 3) is a high total heat flight to certify the heat shield. It is felt that these two types of flights are the minimum required to certify the vehicle for manned flight.

B. MANNED, NEAR-EARTH ENTRY

Seven specific entry conditions were selected for this category, namely C, D, E, F, G, H and I. These conditions were selected to cover all the range of conditions shown in the entry condition spectrum. Various combinations of high loads, high heat, high heat rate, low total heat, maximum and minimum crossrange and downrange, for example, are represented.

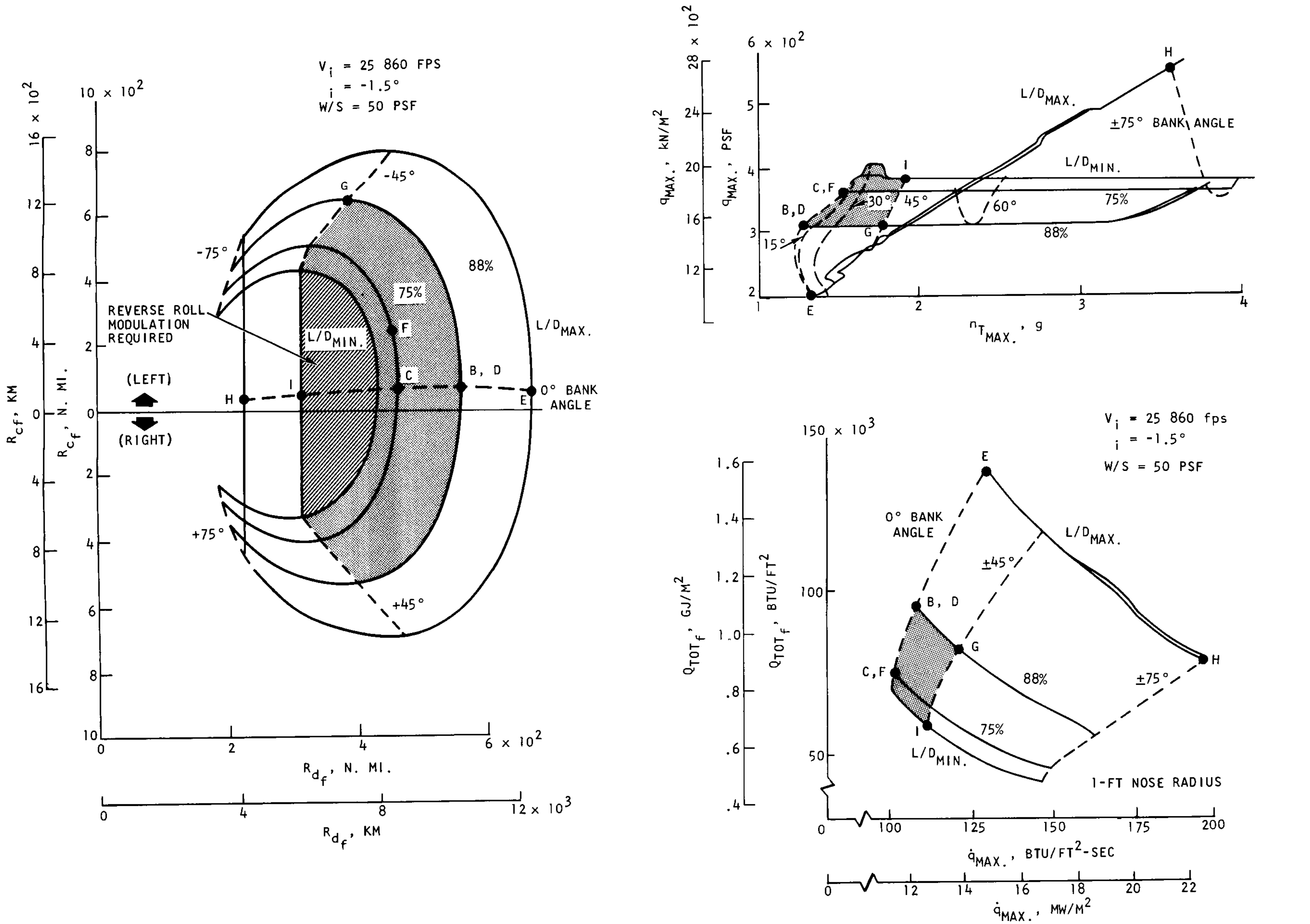


FIGURE 3. ENTRY RESEARCH FLIGHT SPECTRON

TABLE 3

SELECTED ENTRY CONDITIONS

Flight test programs have been planned to accommodate the research tasks and to explore the entry environments representative of near-earth missions. Specific entry conditions corresponding to figure 3 are defined for flight loading analyses as follows.

Condition A (not shown in fig. 3) represents an initial unmanned suborbital flight intended primarily to explore the high airload environment generated by a launch ascent abort at 14 750 fps (4.5 km/sec). This flight terminates with a parachute recovery sequence.

Condition B is an unmanned flight which achieves a high total heat and is intended primarily as a test condition to qualify the heat shield. All flight systems are checked out using this condition, including normal horizontal landing.

Condition C is a nominal manned entry flying to a landing at the center of the landing footprint. The purpose of this condition initially is to acclimate the crew to a normal entry flight. It is used for the first manned test flight and for later flights requiring nominal environments and zero crossrange.

Condition D is a manned entry which achieves a high total heat environment by utilizing a flight toward the toe of the landing footprint.

Condition E is an entry at $L/D_{max.}$ producing a maximum downrange flight (to the toe of the footprint). Maximum entry flight time and total heating are experienced. This condition is attempted after the aerodynamic L/D uncertainty and the guidance and navigation tolerances are better known.

Condition F demonstrates a medium crossrange maneuver (250 N. Mi.) (459. km). This entry requires an average bank angle of 12.5° using 75% $L/D_{max.}$. To improve the mission safety aspects of this flight condition, deorbit is planned for the second orbit.

Condition G demonstrates a high crossrange maneuver (645 N. Mi.) (1184 km). This condition requires an average bank angle of 45° at 88% $L/D_{max.}$. To improve the mission safety aspects of this flight condition, the launch azimuth is changed to 77.7° East of North and deorbit is planned for the first orbit.

TABLE 3.--Concluded

Condition H is an entry at $L/D_{max.}$ with a reverse roll modulated bank angle higher than 45°. This entry produces maximum heating rate and airloads. It also demonstrates minimum downrange maneuver from entry altitude.

Condition I is an entry to demonstrate high airloads and a small downrange from entry. This condition requires entry at maximum C_L and 45° of bank with reverse roll modulation to negate crossrange effects.

An additional entry condition has been planned to accommodate secondary research objectives. This entry condition K entails manned re-entry at 30 000 fps (9.14 km/sec) at an entry angle of -6°. Entry condition S is a special entry which includes a skipping maneuver to expose the flight system to two consecutive high heat rate environments to simulate part of a synergetic maneuver.

TABLE 4

ENTRY CONDITIONS SUMMARY

Flight condition	Description of Flight	Entry Conditions: Inertial velocity, fps	Inertial velocity, km/sec	Entry angle, deg	%, $L/D_{max.}$ (2)	Bank angle, deg	Crew status
A	Special Launch Abort-High Airload Condition	14 756	4.50	-4.6	Min.	0	Unmanned
B(4)	Heat Shield Demonstration High Q_{tot}	25 860	7.98	-1.5	88	0	Unmanned
C	Nominal Entry	25 860	7.98	-1.5	75	0	Manned
D(4)	High Heating, Long Entry Time	25 860	7.98	-1.5	88	0	Manned
E	Maximum Heating, Maximum Downrange	25 860	7.98	-1.5	Approach 100	0	Manned
F	Medium Crossrange	25 860	7.98	-1.5	75	12.5	Manned
G	High Crossrange	25 860	7.98	-1.5	88	45	Manned
H	Maximum Heating Rate, Maximum Air Loads, Minimum Downrange	25 860	7.98	-1.5	Approach 100	±75 (reverse roll modulate)	Manned
I	High Airloads, Small Downrange	25 860	7.98	-1.5	Min.	±45 (reverse roll modulate)	Manned
K(3)	Superorbital - High Heating Rate	30 000	9.14	-6.0	Max.	0	Manned
S	Synergetic Maneuver	25 860	7.98	-1.0	*		

Flight condition	Approximate entry environment: Crossrange, N. Mi.	Crossrange, km	Downrange, N. Mi.	Downrange, km	Entry time, sec	$q_{max.}$, psf	$q_{max.}$, kN/m²	$n_{T\,max.}$, g	Q_{tot} (1), Btu/ft²	Q_{tot}, GJ/m²	$\dot{q}_{s\,max.}$, Btu/ft²-sec	$\dot{q}_{s\,max.}$, MW/m²	Launch and orbit data: Number of orbits	Launch azimuth, deg	Orbit altitude, N. Mi.	Orbit altitude, km
A	0	0	800	1 482	700	1200	57.5	6.0	16K	.68	100	11.3	Special suborbital launch			
B(4)	0	0	5100	9 445	2160	305	14.6	1.3	95K	1.08	107	12.1	3	65.8	80/200	148/370
C	0	0	4700	8 704	1870	360	17.2	1.6	75K	.84	100	11.3	3	65.8	80/200	148/370
D(4)	0	0	5100	9 445	2160	305	14.6	1.3	95K	1.08	107	12.1	3	65.8	80/200	148/370
E	0	0	6750	12 420	2740	200	9.6	1.4	136K	1.55	128	14.5	3	65.8	80/200	148/370
F	250	463	4600	8 520	1830	360	17.3	1.6	73K	.83	100	11.3	2	65.8	80/200	148/370
G	645	1185	3900	7 232	1720	305	14.6	1.8	82K	.93	120	13.6	1	77.7	80/200	148/370
H	0	0	2250	4 170	1350	550	26.4	3.6	77K	.88	195	22.2	3	65.8	80/200	148/370
I	0	0	3200	5 930	1300	380	18.2	2.0	58K	.66	110	12.5	3	65.8	80/200	148/370
K(3)	0	0	2280	4 220	1620	425	20.4	3.5	86K	.98	440	50.0	1	65.8	80/200	148/370
S	*														80/200	148/370

* Enter with 60° bank angle at $L/D_{max.}$ increase α to $C_{L_{max.}}$ when heading changes 2°, entry vehicle will skip and make normal entry

NOTES: (1) Based on 1-ft nose radius.(2) Hypersonic, viscous value. Specific experiments require modulation around this L/D. (3) Data are for roll modulated constant altitude entries. (4) These entry conditions are identical except for crew status.

When generating a flight plan using these entry conditions, certain constraints must be obeyed concerning the sequence to be flown. These prerequisite constraints are shown in table 5.

TABLE 5

ENTRY CONDITION CONSTRAINTS

Code	Entry Condition	Prerequisites
A	High Altitude Abort	--
B	High Total Heat--Unmanned	A
C	Nominal Entry	A, B
D	High Total Heat	A, B, C
F	Medium Crossrange	A, B, C
G	High Crossrange	A, B, C, F
H	Maximum Heat Rate, Airloads	A, B, C
I	High Airloads, Low Downrange	A, B, C
S	Special Synergetic Maneuver	A, B, C, D

C. SECONDARY OBJECTIVES

The contract Statement of Work for this study required the investigation of supercircular entry and synergetic maneuver research as part of secondary objectives. Accordingly, a specific entry condition representative of these types of entry was selected for this category. This condition K, provides environments for supercircular entry research. Entry condition S is for a synergetic maneuvering experiment which provides a skipout capability.

IV. DEFINITION AND JUSTIFICATION

This section describes all the research tasks. A justification form and a definition form are provided for each one. Tasks are grouped according to their technology-oriented classification and, for each of these groups, a summary sheet is presented. These summary sheets are provided for a variety of reasons. Chiefly:

(1) To group research tasks according to technical discipline

(2) To indicate how many of each group fall in the various classification categories

(3) To relate each task to the applicable mission and mission phase.

Other data presented on the summary sheets are man's role in each task and whether the task relates to the primary or secondary objectives of the study. Thus, all the important data for each research task in the group is summarized for ease of use and ready reference. A total of 52 research tasks have been identified and defined. Representative measurement lists for the identified tasks, including the frequency and accuracy of each specific measurement, were compiled to aid in flight test planning and to enable quantitative definition of the instrumentation and data handling subsystem requirements. These lists are provided in the Appendix.

A. CLASSIFICATION

As discussed previously, the research tasks identified were classified according to whether research was pertinent to subsystem technology or a technical discipline. They were further cross classified according to the particular research program objective being met. Table 6 shows, in summary, the results of this classification effort.

B. INDEX

Table 7 is a detailed index of all the research tasks included to aid in finding any particular one.

TABLE 6

DISTRIBUTION OF RESEARCH TASKS

	Subsystem	Technical discipline	Total
Confirmation or Verification	17	10	27
Technology Advance	18	4	22
Pure Research	1	2	3
Total	36	16	52

Examples

Confirmation or Verification

AV-1 Antenna Window Material Test
FM-4 Measure Control Effectiveness
SM-7 Ablator Ascent Heating - Cold Soak

Technology Advance

GN-5 Hypersonic Entry Guidance Techniques
SM-8 Refurbishable Heat Shield Demonstration
FC-2 Adaptive Flight Control System

Pure Research

FM-12 Boundary-Layer Survey
SM-16 Catalytic Wall Experiments

TABLE 7

INDEX TO RESEARCH TASK DEFINITION FORMS

TABLE 7--Concluded

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Ablation Heat Shield Performance and Analysis Correlation	SM-1

1. Technology Status Assessment

The problem is to demonstrate the performance of the heat shield and to verify ground test qualification and analysis procedures. The ablative heat shield design is based on analytical correlated plasma arc tests data. The plasma arc tests are made at constant heating rates, enthalpies, gas properties and gas pressures. The plasma arc can simulate the heating rates at points up to the peak values and the enthalpies are adequately simulated, but gas properties and pressures are only approximately simulated. During these tests, temperature-time histories at various levels through the ablator are measured and, after heating, char depth and density variations are measured. An analytical design model is developed using thermophysical chemical property tests, char depth and density variations, along with well-known heat balance relationships, to predict the time-temperature histories and simulate the char and surface recession characteristics of the ablator.

This analytical model is then used in conjunction with the predicted heating rates, altitude, velocity and pressures to design the heat shield for the entry vehicle.

The problem is: Do the plasma arc tests adequately simulate the actual environment and does the analytical model adequately predict the ablator performance? Safety factors are normally added to the heat shield design to provide for technological uncertainties in the ablator and design environment.

2. Justification for Test on the Research Vehicle

A flight test of an unmanned, full-scale instrumented entry vehicle, along with the evaluation of the heat shield after entry, must be accomplished prior to manned flight to prove vehicle safety for man and to obtain data to demonstrate heat shield design capability for future flights with increased severity.

3. Crew Tasks During Experiment

This is a safety of flight test to qualify the vehicle for man, therefore this task must be successfully accomplished on an unmanned flight.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-1
Ablation Heat Shield Performance and Analysis Correlation	RANKING 1

OBJECTIVE

To qualify the heat shield for manned flight and to provide data for analytical model correlation.

DESCRIPTION

The ablation analysis techniques will be developed by defining an analytical model which typifies the chemical processes, heat transfer mechanisms and material property data determined from laboratory experiments. The analysis will then be corrected and/or verified by correlation with plasma arc re-entry heating simulation tests. The ground tests correlations are primarily limited to square pulse heating where the environmental parameters of heating rate, enthalpy, pressure and surface shear conditions cannot be simultaneously simulated.

The heat shield panels will be instrumented during flight test to monitor surface recession, char line recession, surface temperature, internal temperature distribution, structure temperature and local pressure and heating rates. These data in conjunction with postflight measurements will be utilized to evaluate the analytical methods and computer routines that were developed for application to the transient flight conditions. The flight test data will be used to substantiate and provide additional information in areas of uncertainty. The analytical methods can then be modified to reflect more reliable predictions of the ablation materials performance.

This task is to be programmed with Research Task FM-8.

At completion of tests data analysis, suitable safety factor requirements and design criteria will be developed.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type B (Several angles of attack should be used.)	Min. 1
Type C	Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperatures	Thermocouple	400
Surface recession	Breakwire type surface recession gage	20

NOTE: This test must be performed with the heating and pressure distribution test.

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Ablative Heat Shield Joints	SM-2

1. Technology Status Assessment

The ablative heat shield design used to provide a simple refurbishment capability requires the utilization of a number of joints, for panel removal and replacement. During ascent heating, space vacuum soak and subsequent entry, these joints are required to withstand some mechanical and thermal strains. The primary problem is what are the magnitudes of these strains and the degree of joint complexity required to prevent adverse heating and flow conditions from occurring.

2. Justification for Test on the Research Vehicle

Full sized panel must be evaluated if the thermal and mechanical strains are to approximate those of actual flight. Complete testing of full sized panels under the heating and cold soak conditions that occur during entry cannot be accomplished without extensive facility development.

Flight tests on small unmanned vehicles could be conducted to compare different panel joint configurations and define design requirements. However, these tests are not warranted on their own merit, but are justified as a part of the major heat shield qualification and development tests on the larger manned vehicle.

3. Crew Tasks During Experiment

None.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-2
Ablative Heat Shield Joints	RANKING 15

OBJECTIVE

To define the magnitudes of joint thermal and mechanical strains and the degree of joint complexity required to prevent adverse heating conditions from occurring.

DESCRIPTION

The use of refurbishable heat shield panels requires joints which possess ablative thermal protection capability comparable to the primary shield material. The heat shield panels will have joints oriented in various positions with respect to the flow conditions. In addition, the joints must withstand the thermal stresses and strains induced during the orbital and re-entry heating environments.

Different types of joint designs and ablative gap filler materials will be evaluated and selected on the basis of space and re-entry heating simulation tests. In addition, the gap openings which can be tolerated without introducing significant subsurface heating will be defined for joint configurations normal and parallel to the flow.

During initial vehicle flight tests, the heat shield panel joints will be instrumented with strain gages, heat flux sensors and/or thermocouples to determine the most efficient joint configurations. Also, postflight analysis of the joints will be instrumental in substantiating the designs.

This task must be preceded by at least one flight on which Research Task SM-1 is programmed.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C (vary angle of attack) or Type F	Min. 1 Max. 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouple	40
Surface cracking	Breakwire circuits	20
Substrate panel strain	Strain gages	40

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
	0	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Ablator Materials Comparison	SM-3

1. Technology Status Assessment

The conduct of a lifting entry flight research vehicle program may require several years. During this period, the state of the art in ablation heat shields will be improved and new, improved materials will be developed. Any flight research program that takes place over a period of time must have the capability of flight testing new materials that are developed during the course of the program.

The specific problem is to provide a capability for performing ablative material heat shield tests during the course of the program.

2. Justification of Test on the Research Vehicle

It is important to future operation applications that the research vehicle flight test be performed on the latest state-of-the-art developments and not on outdated items.

3. Crew Tasks During Experiment

Man can be used to monitor the test instrumentation data and vary the test parameters if desired.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-3
Ablator Materials Comparison	RANKING 25

OBJECTIVE

To evaluate new or improved ablator materials.

DESCRIPTION

See attached sheet (page 30)

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable except condition "A"	All manned flights

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Heat flux	Calorimeter	10
Temperature	Thermocouple	80
Surface recession	Breakwire-type gage	5
Pressure	Pressure transducer	10

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Replacement ablator material panels.	WEIGHT (LB): ±10 (4.54 kg)
	POWER (WATT): 0

DESCRIPTION: Task SM-3

The basic structural design of the vehicle will be accomplished with the concept of providing the capability of conducting "test bed" experiments. Provisions will be made to attach heat shield panels of different or newly developed ablator materials whose thermal performance and thickness requirements vary significantly from the primary shield. The test panels will be designed for installation without compromise to the aerodynamic surfaces or structural temperature design criteria.

Initially, candidate ablator materials will be subjected to air-arc-plasma re-entry heating simulation testing and trajectory analysis to qualify the materials for the proposed flight thermal conditions. In addition, the candidate ablator material panels will be designed and ground tested to simulated space and load environments to demonstrate mechanical integrity consistent with vehicle design criteria.

The qualified candidate ablator materials will be flight tested and compared with the thermal performance of proven materials. The general areas for comparing the materials will consist of evaluating the overall ablated surface characteristics for maintaining aerodynamic surface requirements, density and mass loss, surface recession (if any), char line recession, temperature distribution and consistency of performance with the predicted.

After completion of communication blackout experiments, a special problem would consist of evaluating ablators developed to reduce boundary layer ion contamination.

This task must be preceded by at least one flight on which Research Task SM-1 is programmed.

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Movable Surface Heat Shield Design Problems (Coves, Gaps and Seals)	SM-6

1. Technology Status Assessment

Movable control surfaces on lifting entry vehicles present significant heat shield design problems. If hot structures or radiative heat shields are used, the peak heating rates and operation temperatures impose severe design restrictions. If ablative heat shields are used, the heating rate and operating temperatures are not major problems. However, problems are encountered in maintaining gap dimensions, cove seals and surface contours in the presence of ablating surfaces.

If air flow is allowed to move freely through the cove during entry, the heating increases and the flap effectiveness is changed. A design application on the PRIME vehicle utilizes high density, pressure molded ablators, machined to small tolerance dimensions in the flap cove and edges. This application, while considered effective, is extremely heavy. Some of the heat shield weight in this area is added because of uncertainties in heating and seal requirements. Because of this weight being considerably aft of the cg, additional ballast is also required.

The specific problem is to define the movable surface cove, gap and seal requirements for entry vehicle design, such that the minimum system possible to provide the required functions and safety can be developed.

2. Justification for Test on the Research Vehicle

To completely evaluate the flow effects on cove and gap heating, seal requirements and their effects on control surface effectiveness and hinge moments, a full-sized manned flight test is required.

Wind tunnel tests can be used in defining the problem and in evaluating design requirements, but they do not have the capability to provide the required heating and flow condition to evaluate the ablation and heat shield effects.

Limited evaluation tests could be conducted on small unmanned flight test vehicles. However, man's contribution to the tests would be lost and because of the size, some scale effects would be involved.

3. Crew Tasks During Experiment

During the flight tests, man can be used to vary the cove seal, and to monitor gap heating and flap effectiveness. Man's ability to vary parameters and to monitor critical ones, such as flap effectiveness, will allow a larger range of test variables to be safely evaluated.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-6
Movable Surface Heat Shield Design Problems (Coves, Gaps and Seals)	RANKING 14

OBJECTIVE

To define the magnitude of the heating and pressure in the movable surface cove areas as a function of the gap seal clearance and to evaluate potential heat shield design alternatives.

DESCRIPTION

Ground test will be used to develop a flap cove heat shield that is considered to be conservatively designed. A variable pressure seal will be used in the design.

The first unmanned heat shield qualification flight will check out the validity of the design and collect temperature, heating rate and pressure data. Control surface hinge moments and dynamic responses will also be monitored for this flight.

If data indicates design is truly conservative, a subsequent manned flight will fly the same area cove design. At this time, the man will vary the seal clearance and monitor the control surface effectiveness, dynamic response and hinge moments. Recorded data will include temperatures, pressures and heating rates.

Based on the results of the first two tests, a study will be made to define an improved design for evaluation on a subsequent flight. Similar measurements will be made on this test. A critical analysis of the design will be made after complete review of all test data.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type B	Min. 1
Type C or F	Max. 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Heat flux	Calorimeter	20
Pressure	Pressure transducer	20
Temperature	Thermocouple	100
Control surface hinge moment	Load cell	4
Control surface position	Linear displacement gage	10
Control surface dynamic response	Accelerometer	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
(1) Variable gap flap cove seal, electric screw cam driven.	WEIGHT (LB): 50 (22.7 kg)
(2) Auxiliary cooling system, flap cove area, water (20 lb) tank, N_2 gas expulsion system	POWER (WATT): 30

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Ablator Ascent Heating, Cold Soak and Subsequent Entry	SM-7

1. Technology Status Assessment

If during ascent, the ablator is heated to a temperature sufficient to cause some decomposition, the low temperature elastic properties of the ablator are adversely affected. If the extreme cold soaks that occur with extended orbit stay times or high altitude orbits are encountered, cracking of the ablator surface could occur. The extent to which these cracks will open and what happens to them during subsequent entry heating requires evaluation.

One school of thought is that during the initial heating of entry, the thermal expansion of the ablator will close the cracks sufficiently to prevent any increase in local heating. If the cracks should remain open some increase in heating will occur and if the flow direction and the crack direction coincide, this increase could become large.

The specific problem is: Does this cold soak condition (after ascent heating) present a severe design restriction or problem for ablative heat shields ?

2. Justification of Test on the Research Vehicle

Because of the size limits of current facilities and their ability to simulate the complete environment, complete verification cannot be achieved without flight test. Vehicle size is a significant parameter and must be held to near the size for operational application.

If after the initial unmanned temperature survey flight and ground evaluation tests, the problem is considered sufficiently severe to warrant an orbital test flight that approaches limiting cold soak conditions, this could be considered a flight safety item and an additional unmanned flight test would be required.

3. Crew Tasks During Experiment

Man can be used to monitor test instrumentation and, if orbital stay time is adequate, possibly make an extravehicular survey of the heat shield prior to entry.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-7
Ablator Ascent Heating, Cold Soak and Subsequent Entry	RANKING 22

OBJECTIVE

To determine the extent of ablator degradation that occurs during ascent heating and evaluate its effect on material properties and the ability of ablator to withstand the orbital cold soak condition without deleterious cracking.

DESCRIPTION

During the initial unmanned heat shield qualification flight, the ablator surface and internal temperature histories will be determined for the ascent, space and entry flight. Substrate panel strains and ablator cracking will also be measured.

These data will be used with ground tests and analysis to establish the condition of the ablator at the end of ascent heating. The susceptibility to cracking during extreme cold soak will be determined and evaluated by elemental ground tests. If indicated, plasma arc test will be conducted of cold soaked specimens that have been preheated to simulate ascent heating.

If major problems with ablator cracking are encountered, extensive material development and evaluation of alternative ablator materials or design solutions will be made on subsequent flights.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type B	Min 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouples	100
Strain	Strain gages	20
Cracking	Breakwire circuits	40

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
	0	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Refurbishable Heat Shield Demonstration	SM-8

1. Technology Status Assessment

For operational entry vehicles, one of the most significant factors affecting turn-around time and cost is the heat shield. A concept has been developed that offers the potential of providing a thermally efficient heat shield as well as one that can be easily refurbished between flights. Until this has been accomplished and the vehicle is re-flown, some questions will remain about its development status and turn-around cost.

The primary problem is to demonstrate the refurbishability of an ablative heat shield and to establish turn-around costs and time schedule. The effect of refurbish-ability on reliability and heat shield quality must be established.

2. Justification for Test on the Research Vehicle

On any program, if the vehicle refurbishment cost and turn-around time are low enough, it is economical to refly the same vehicle several times rather than having a new vehicle for each flight.

3. Crew Tasks During Experiment

None.

RESEARCH TASK DEFINITION

TASK TITLE
Refurbishable Heat Shield Demonstration

TASK NO. SM-8

RANKING 17

OBJECTIVE
To demonstrate the heat shield refurbishment capability and to establish turn-around time and cost.

DESCRIPTION

During the heat shield design operation, the refurbishment capability will be designed into the heat shield.

After each flight test is conducted and the reflight turn-around cycle started, all cost, turn-around problems and schedule items will be monitored and recorded. Also, any design problems which occur will be noted.

After the entire flight test program, these data will be collected and evaluated to provide historical data for future operational systems. A critical evaluation of the heat shield concept will be conducted and potential improvement areas noted.

FLIGHT CONDITIONS
Any entry condition is suitable.

NO. OF FLIGHTS
All refurbished and reused flights

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Ground measurements only	No flight instrumentation planned.	

AIRBORNE EQUIPMENT OTHER THAN SENSORS

WEIGHT (LB)
0

POWER (WATT)
0

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

D. RADIATION HEAT SHIELD	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
SM-9 Radiation heat shields		X		X	X	X	X	X	X					X			X		X	
SM-10 Radiation heat shield joints		X		X	X	X	X	X	X					X			X		X	
SM-11 Structural cooling		X		X	X	X	X	X	X	X	X			X			X		X	
SM-12 Ablator overcost on radiative panels		X		X	X	X	X	X	X					X			X		X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Radiation Heat Shields	SM-9

1. Technology Status Assessment

When compared to the current double wall ablative concepts, radiation heat shields do not present a significant weight benefit and do result in a cost increase for lifting body entry vehicles of the L/D = 1 class. However, for higher L/D vehicles and for cases where extensive reuse is required, radiation heat shields have the potential of being the lightest and cost competitive. Also, for vehicle applications where synergetic maneuvers are required, radiation heat shields must be utilized if such maneuvers or vehicle applications are to be feasible.

Radiation heat shields are heating rate limited and present operational restrictions if a minimum weight system is to be provided. Also, radiation heat shields using refractory metals present service and safety problems because of the oxidation characteristics of the metals. Extensive ground and flight test of these materials must be conducted before they can be considered operational.

2. Justification for Test on the Research Vehicle

Sufficient test capability is available to qualify radiative heat shields for one flight application. However, ground test facilities do not adequately simulate the flight environment to reliably evaluate the material and oxidation protection coating reuse capability.

It is not possible to properly evaluate radiative heat shield panels on small unmanned vehicles because the smaller vehicle has significantly higher heating rates and proper application cannot be provided.

3. Crew Tasks During Experiment

Man can be used to monitor the radiative heat shield panels temperatures during the flight tests. By using man to perform this function, it will be possible to control the temperature of the radiative heat shield panels and thus more fully evaluate the system. This control is obtained by adjusting the vehicle attitude to obtain desired altitude and velocity conditions.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-9
Radiation Heat Shields	RANKING 24

OBJECTIVE

To evaluate the thermal protection capability and the reuse potential of radiative heat shield.

DESCRIPTION

See attached sheet (page 42)

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any flight condition except A and B is suitable.	Max. 10 Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperatures	Thermocouples	200 (first two flights) 50 (subsequent flights)
Pressure	Pressure transducer	20

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Replacement radiative panels	WEIGHT (LB): +10 (4.54 kg) POWER (WATT): 0

DESCRIPTION: Task SM-9

Materials, oxidation protection coatings, and fabrication techniques will be surveyed to establish the state of the art in radiation heat shield technology. Design and tradeoff studies will be made to establish the best systems. Detailed ground evaluation and qualification tests will be conducted on these systems. The flightworthy systems will be identified.

A number of areas on the vehicle will be selected where the radiation heat shields could be utilized. The panels will be tested in areas where the heating rates are such that catastrophic failures will not occur. First flight test of radiative heat shields will be after the heating rate distribution test (FM-8) has been completed. Several panels of each alloy and oxidation protection coating will be installed on one or more of the vehicles (exact number depends on how many total research flights are conducted). An active cooling system is required for these panels.

Radiative panels of nonmetallic materials (such as graphite, ceramics, etc.) and their associated heat shield concepts will be flight tested if justified by analysis and ground test.

During flight, temperature histories of the radiation heat shields will be monitored and recorded. After flight, all panels will be removed and a detailed inspection conducted. At least one panel of each alloy and coating will be destructively tested to determine the expected life capability of the remaining panels. The remaining panels, if acceptable, will be replaced on the vehicle for the next flight. This process will be repeated after each flight. The panels will be flown on as many of the remaining program flights as possible.

At the end of the flight test program, the data will be utilized to define the capabilities of the radiative heat shield as well as inspection and replacement requirements.

Provisions will be made to evaluate new and improved coatings, materials and concepts that might be developed during the course of the flight test program.

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Radiative and Radiative-to-Ablative Heat Shield Joints	SM-10

1. Technology Status Assessment

Radiative heat shields are purposely modularized to minimize thermal stress problems associated with heated structures. By nature, the modular panels require sliding expansion joints that are exposed to the boundary layer gas flow. Large open joints would create adverse heating problems and flow conditions. The effects of joint geometry on heating and flow conditions must be evaluated in ground test prior to flight application. However, their effects on heating of large surfaces and on flow transition cannot be completely evaluated with ground test.

Another problem associated with radiative heat shield application is the interface between radiative and ablative panels: specifically, how is it possible to maintain smooth transition between concepts and materials without thermal stress and heat short problems. The silicone base ablators that do not exhibit surface recession of heating rates below 90 Btu/sq ft-sec make this a design and arrangement problem rather than a surface transition problem.

Extensive ground tests are required to develop acceptable joint geometry that incorporates both heat shield integrity and flow field effects. Because of ground test limitations, they must also be evaluated in flight.

2. Justification for Test on the Research Vehicle

This test is done in support of the radiative heat shield studies. It represents one of the most significant design problems associated with radiative heat shields.

3. Crew Tasks During Experiment

Man can be used to monitor the radiative heat shield joint temperature and flow effects.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-10
Radiative and Radiative-to-Ablative Heat Shield Joints	RANKING 38

OBJECTIVE

To define the design requirements for radiative heat shield joints and evaluate several joint configurations to define the required joint complexity.

DESCRIPTION

Candidate heat shield joint configurations will be incorporated on standardized panels to evaluate combined environmental factors such as vibration, air load and temperature effects on the joint designs. The joints will be instrumented with thermocouples, deflectometers and strain gages (if available).

As more instrumentation and the control of environmental factors are possible with ground tests, the candidate joint designs will be subjected to laboratory tests prior to flight test. These tests will assist in the design and the fabrication development of the flight test designs.

By closely coordinating the instrumentation locations of the flight and laboratory test designs, a high degree of data correlation will be possible. Also, the instrumentation requirements for the flight test designs will be reduced. The data from these tests will be used for design verification and selection of the optimal design(s).

This task is to be conducted with Research Task FM-9 (Radiation Heat Shields).

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any flight condition except A and B is suitable.	See SM-9

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouples	20
Deflection	Linear deflection gage	10
Strain	Strain gage	24

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
Alternative heat shield joint combinations.	WEIGHT (LB): 0
	POWER (WATT): 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Active and Passive Structural Cooling	SM-11

1. Technology Status Assessment

Some structural cooling techniques must be used with radiation heat shields if they are to be weight competitive with ablation heat shields. Radiative heat shield systems that use combinations of insulation and structural cooling are lighter than those based on a simple insulation system.

There are several active and passive cooling systems that can be utilized; before the final selection can be made, extensive design tradeoff studies and ground tests must be accomplished.

Structural cooling systems must be developed and flight tested in conjunction with radiation heat shield. Design tradeoff studies and ground test qualification must be accomplished. These tests must be planned and the cooling passage requirements built into the structure at the time of fabrication of the research vehicle.

2. Justification for Test on the Research Vehicle

Structural cooling systems must be utilized during the flight test of radiative heat shield panels. Ground test can be used to flight qualify selected system design and help make alternative system tradeoff tests. It is probably advisable to flight test an active system and a passive system if qualified flight hardware can be developed for the passive system.

3. Crew Tasks During Experiment

In the design studies of active cooling systems, redundancy is usually provided in the coolant passages to improve reliability. Man can be used in the flight test to monitor coolant flow temperature and make necessary adjustments to maintain proper temperature, thus increasing system reliability without complete system redundancy.

RESEARCH TASK DEFINITION

TASK TITLE

Active and Passive Structural Cooling

TASK NO. SM-11

RANKING 42

OBJECTIVE

To define the design requirement and to evaluate active and passive structural cooling concepts.

DESCRIPTION

Design tradeoff studies will be conducted on the better active and passive structural cooling systems. The best systems will be evaluated through ground test and qualified for flight test.

System capability and requirements for both systems will be built into the structure. Remaining equipment and instrumentation will be installed at the time of flight tests. During flight test, the cooling panel temperatures at several levels in the heat shield system will be recorded, as well as the coolant flow rates and temperatures. Aero data for the flight must be available and insulation cavity pressures recorded.

After the flight test the results will be evaluated and appropriate criteria and design requirements for structural cooling system developed. The systems efficiency and operational applicability will be evaluated.

This task must be conducted in conjunction with FM-9 (radiation Heat Shields) in order to evaluate the cooling system.

FLIGHT CONDITIONS

Type C or F

NO. OF FLIGHTS

Min. 1

Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouple	100
Pressure (air)	Pressure transducer	10
Pressure (coolant)	Pressure transducer	10
Coolant flow rates	Flowmeters	4
Coolant pump power	Volt-amp meter	2

AIRBORNE EQUIPMENT OTHER THAN SENSORS

(1) Coolant pump
(2) Coolant tank and plumbing
(3) Heat exchanger
(4) Valves and associated hardware
(5) Coolant: 60 lb (27.2 kg) H_2O

WEIGHT (LB)

125 (56.7 kg)

POWER (WATT)

0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Ablator Overcoat on Radiative Panel	SM-12

1. Technology Status Assessment

Under certain ascent abort environments, radiative heat shields are severely penalized by the high peak-short time heating rates that can occur. One approach to relieve this problem is to coat the panels with a thin ablative layer that is effective in absorbing the high heat pulse.

Some of the questions that arise from this application are: How high a bond temperature can be considered to effectively provide protection ? When it does come loose, is it in large chunks, small flakes or what ? and Will these particles be harmful to structure aft of this area ?

Ground simulation tests cannot answer this because of size and environmental simulation limits. However, some ground tests can be made to screen material and develop design requirements for flight safety.

Through flight and ground test, the question concerning bond temperature and separation must be answered prior to operation application of this concept.

2. Justification for Test on the Research Vehicle

This test is conducted in support of the radiative heat shield studies to provide a technique for protecting the panels against the peak heating rates of the ascent abort environment. Utilization of an ablative overcoat on the radiative panels will increase the operational flexibility of the heat shield system.

Ground test facilities do not have the capability to completely evaluate the performance and design requirements of the ablator overcoat protection.

3. Crew Tasks During Experiment

Man can be used to monitor the instrumentation during test and to evaluate the vehicle performance as the ablator burns off of the radiative panels or when bond failures start to occur.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-12
Ablator Overcoat on Radiative Heat Shields	RANKING 39

OBJECTIVE

To evaluate the potential of using an ablative overcoat on radiative heat shields to protect against ascent abort heating.

DESCRIPTION

Ablative materials and thermal design studies will be conducted to select a charring and a subliming ablator. These two will be extensively evaluated and ground tested to determine compatibility with the radiative panel materials, their surface recession characteristics and overall thermal performance.

After a flight test that has established heating rates and distributions and also, after one that has evaluated radiative panels, two selected ablative materials will be evaluated on superalloy radiative heat shield panels. Thermocouples and breakwire circuit instrumentation sensors will be used to evaluate thermal performance, bond failure limits and char separation characteristics.

Flight test data will be evaluated and ablator capabilities established. On subsequent entry flights, the ablative coatings will be evaluated on the columbium and tantalum radiative heat shields.

This task must be preceded by two flights on which Research Task SM-9 (Radiation Heat Shields) is programmed.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type H	Min. 1 Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouple	40
Bond separation	Breakwire-type gage	20

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Ablative overcoat on radiative panels	WEIGHT (LB): 0 POWER (WATT): 0

RESEARCH TASK SUMMARY

E. GENERAL HEAT SHIELD		Category			Missions								Phase				Man			Work Statement	
		Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
SM-5	Insulation cavity pressure	X			X	X	X	X	X	X	X	X	X	X	X			X		X	
SM-13	Heat shield instrumentation sensor studies		X		X	X	X	X	X	X	X	X	X	X	X				X	X	
SM-14	After heat effects	X			X	X	X	X	X	X	X	X			X			X		X	
SM-15	Transpiration cooling systems		X		X	X	X	X	X	X	X	X			X			X		X	
SM-16	Catalytic wall experiments		X		X	X	X	X	X	X	X	X			X				X	X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Insulation Cavity Pressure	SM-5

1. Technology Status Assessment

The conductivity of the insulation materials used in the refurbishable heat shield and for the radiative heat shield design is very pressure sensitive. The conductivity varies by an order of magnitude when going from a hard vacuum to a pressure of one atmosphere at sea level. In flight, the dynamic pressure on the windward vehicle surface is greater than the absolute pressure at that particular altitude. The exact pressure and pressure history in the insulation cavity is not known and it has been assumed as the pressure for 100 000-ft (30.48 km) altitude in determining the insulation conductivity used for design purposes. This is probably conservative since the heating is essentially completed before the vehicle reaches a 100 000-ft (30.48 km) altitude.

Another unknown in the case of the ablative heat shields is the effect on conductivity of gases that escape from the ablator and substrate panel during the decomposition process.

If the gases and boundary layer pressures have an adverse effect on the conductivity, then a very thin metal foil layer can be used between the insulation and panel to prevent gases from entering the insulation.

The specific problem is: Are the pressures and insulation conductivities used in the design overly conservative and can they be reduced or must some gas barrier be used to provide the minimum weight system ?

2. Justification for Test on the Research Vehicle

This test could be conducted on an unmanned vehicle; however, the vehicle size and heat shield configuration will have an effect on the test results. Wind tunnel or other ground tests do not have the capability to simulate the required flight environment.

The test is justified because a knowledge of the pressure history in the insulation cavity will increase design reliability and has the potential of offering a significant insulation weight savings.

3. Crew Tasks During Experiment

Man can be used to monitor the test instrumentation and vary flight conditions to determine sensitivity of the cavity pressure as a function of flight conditions.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-5
Insulation Cavity Pressure	RANKING 23

OBJECTIVE

To determine the effective pressure in the insulation cavity and to evaluate different techniques of preventing boundary layer and ablator decomposition gases from entering the insulation.

DESCRIPTION

Pressure gages will be installed at a number of places in the heat shield insulation cavity. Some of these gages will be symmetrically placed on the vehicle. A thin metal foil gas barrier will be used between the heat shield panels and the insulation over some of the symmetrically placed gages.

Pressures will be recorded during all phases of the research flight operation. During ascent and entry, the pressures will be measured at time intervals of 20 seconds and during space travel at intervals of 5 minutes. Thermocouples will also be used to measure the temperature drop across the insulation at selected points throughout the flight.

After flight, the cavity pressures will be evaluated and an effective pressure time history will be developed for determining insulation design conductivity.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A is suitable.	Min. 1 Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Pressure	Pressure transducer	20
Temperature	Thermocouple	40

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)
Metal foil barrier in heat shield air gap	+10 (4.54 kg)
	POWER (WATT)

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Heat Shield Instrumentation Sensor Studies	SM-13

1. Technology Status Assessment

Heat shield instrumentation sensor development is behind the capability needed for entry flight tests. This is a result of limited material capabilities as well as development funds. During the course of a flight research test program such as this, a considerable improvement in the state of the art could be expected. Some procedure should be established for flight evaluation as the new capability is developed.

During the development phase of the program, considerable effort must be expended to improve the sensor development so the required measurements could be made to an acceptable accuracy level.

An improvement in the heat shield instrumentation sensor development is required and must be evaluated during the course of the flight research program.

2. Justification for Test on the Research Vehicle

This is a flight test that is justified only on the basis that the data is needed to provide better information from the other flight tests. Ground tests will be used in the initial evaluation and qualification of the instrumentation sensors. However, flight must be conducted to provide the proper environment.

3. Crew Tasks During Experiment

Man cannot make any direct contribution to the test but he can be used to monitor the results and, if necessary, vary the test parameters.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-13
Heat Shield Instrumentation Sensor Studies	RANKING 40

OBJECTIVE

To perform flight test evaluation of new developments in heat shield instrumentation sensors.

DESCRIPTION

A series of flight and laboratory tests to evaluate instrumentation sensors will be accomplished. New sensors will be initially evaluated in a laboratory on standardized specimens for accuracy, repeatability, reliability and compatibility. The laboratory test data will provide the basis for evaluating the flight test performance of the new sensors.

The candidate sensors will be installed on standardized parts (identical to laboratory specimens) for flight test evaluation. Competitive sensors will be located in similar areas that will be subjected to the same environment.

Possible sensors to be evaluated will be thermocouples, recession gages, strain gages, deflectometers, calorimeters, accelerometers, etc.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any flight condition except A is suitable	Min. 2 Max. 6

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouples	6
Stress	Strain gages	4
Deflection	Linear deflection gage	5
Char and ablation recession	Breakwire type recession gage	8
Vibration	Accelerometers	8
Heat flux	Calorimeters	4

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)
	0
	POWER (WATT)
	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
After Heat Effects	SM-14

1. Technology Status Assessment

The peak structural and internal vehicle temperatures occur after the aerodynamic heating is completed. In some instances and vehicle areas, this can happen up to 10 to 15 minutes after the vehicle is sitting on the ground. This occurs because of the heat stored in the heat shield during the heating portion of flight.

A considerable amount of heat shield and insulation weight is provided to protect the structural and internal areas from temperatures that would destroy their integrity.

In the analyses that can be accomplished in preliminary design or study programs, certain simplifying and conservative assumptions must be made. A complete study of the vehicle heat loss to the air after heating and while sitting on the ground has not been conducted. However, limited studies do indicate there is a significant problem.

There are several approaches that could be utilized to significantly reduce the entry vehicle heat shield weight. These might include: forced air cooling while in flight, forced air cooling while on the ground, active cooling structure with ground support equipment and others.

2. Justification for Test on the Research Vehicle

The factors affecting this problem are not peculiar to full-sized vehicles. However, the magnitude of the after heat problem and benefits of a cooling system to reduce heat shield insulation weights will be affected by size and the addition of man.

A large percentage of the heat shield weight is involved in protecting the vehicle from the after heat effect. Better understanding of the magnitude of the problem and the design requirements that influence potential cooling system tradeoff studies are required before the value of the weight savings can be established. Flight tests data are required to conduct the design tradeoffs and subsequent flight test on cooling techniques.

3. Crew Tasks During Experiment

Man can be used to monitor test data and report on the physiological problems associated with the after heat effects.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-14
After Heat Effects	RANKING 35

OBJECTIVE

To determine the extent of the after heat problem and to evaluate different cooling techniques for reducing the heat shield requirements.

DESCRIPTION

During the initial unmanned flight test the temperature histories of the structure and selected internal vehicle points will be monitored until after they have reached their peak values. These histories along with the heat shield analysis data will be used to establish design requirements and feasibility of a cooling system for relieving the after heat soak effects and reducing heat shield weights.

Design tradeoff studies will be made of alternative cooling systems, the best one selected and necessary hardware developed and qualified through ground test.

Flight test evaluation of the cooling system will be conducted on a later flight. Again, a similar thermocouple instrumentation will be used to evaluate the system performance.

After the flight test, an evaluation will be made of the data and feasibility for utilization on the remaining vehicle flights and future application established.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type B	1
Any flight condition except A	1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature NOTE: Record until 30 min after vehicle is on ground.	Thermocouple	200

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
(1) Foil air passage control in heat shield insulation air gap.	WEIGHT (LB) 35 (13.6 kg)
(2) Boundary layer--forced air bleed system.	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Transpiration Cooling Systems	SM-15

1. Technology Status Assessment

The thermal efficiency of transpiration cooling systems is not as good as that of our ablative or radiative systems. However, it does offer certain advantages that neither of those systems have--the ability to withstand extremely high heating rates and still maintain original surface contours. This capability is advantageous to high L/D vehicle. For vehicles making synergetic maneuvers, transpiration cooled leading edges and nose caps offer the only answer to maintain surface contours during two heat pulses (if heating rates exceed radiative heat shield capabilities).

There are many system functions and secondary effects that must be evaluated through ground tests and flight tests before a transpiration cooled heat shield could be placed on a operational vehicle. These are: heating rate sensors to control coolant flow, system operational efficiency, surface temperature requirements, effects of mass injection on flow transition, effects of mass injection on afterbody heat transfer, and could leading edge mass injection be used to cool the entire vehicle surfaces.

The primary problem is the definition of transpiration cooling system design criteria and the development and flight test of efficient hardware.

2. Justification for Test on the Research Vehicle

Wind tunnel and other ground test facilities can be used in a limited evaluation of the effects of mass injection on heating and flow. However, a complete evaluation cannot be made with ground tests because of their inability to simulate the varying transient environment the system is exposed to in flight.

Some of the parameters that must be monitored in the tests are a function of size and should be evaluated on a vehicle whose size is near that expected for the operational application.

3. Crew Tasks During Experiment

For the transpiration cooling experiment, man can be used to monitor panel heating and adjust mass injection flow to control temperature or be used to provide a safety redundancy to this function if it is controlled through an automated system. Man can also be used to evaluate the effects of mass injection on control system effectiveness and can introduce into the tests a larger variation of test parameters than can be safety programmed for an automated system.

RESEARCH TASK DEFINITION

TASK TITLE	
Transpiration Cooling Systems	TASK NO. SM-15 RANKING 47

OBJECTIVE

To evaluate the thermal protection potential of transpiration cooling systems and to evaluate the effects of the mass injection on the afterbody heating, flow transition and control effectiveness.

DESCRIPTION

Extensive design tradeoff studies and ground tests will be made to select the best passive and the best active transpiration cooling systems materials, flow control and heat sensing systems.

A transpiration cooled panel will be placed in at least two locations on the vehicle; one will be on the lower surface center line and the second on the fin leading edge.

Heating rate sensors, pressure transducers and other instrumentation to detect the effects of the mass injection on afterbody flow, heating and flow transition will be utilized. Varying amounts of coolant will be injected at several angles of attack while maintaining essentially the same dynamic pressure. Also, during these tests, control surface deflections, hinge moments and effectiveness will be evaluated.

After the flight test has been made, a detail study of the test results will be conducted to establish the usefulness of transpiration cooling and its effect on the vehicle flow field.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type D (Conditions A, B, D, I or H are suitable but yield data of lower value)	1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouple	100
Pressure	Pressure transducer	25
Heat flux	Calorimeters	25
Control positions	Potentiometers	10

AIRBORNE EQUIPMENT OTHER THAN SENSORS

(1) Coolant tank
(2) Coolant pump
(3) Coolant plumbing and hardware
(4) Transpiration cooled heat shield panel
(5) Heat sensing--coolant flow control system
(6) Coolant (approx 20 lb)

WEIGHT (LB)
80 (36.3 kg)

POWER (WATT)
100

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Catalytic Wall Experiments	SM-16

1. Technology Status Assessment

In the regimes of hypersonic flight, an appreciable fraction of the dissociated species of nitrogen and oxygen is present in the free stream. The recombination of these dissociated atoms at the surface is an exothermic reaction which can increase the heat transfer to the surface. The degree and the rate of these recombination reactions are directly dependent upon the catalyticity of the thermally exposed surface.

Calculations in scientific papers indicate that a reduction in the heat transfer rate of the order of fifty percent could be realized in local areas by inhibiting or preventing the atom recombination at the surface. The limited amount of experimental data substantiates the theoretical results and indicates that large reductions in the heat transfer rate may be realized if suitable noncatalytic surfaces are used. A complete understanding of the effects of wall catalyticity on heat transfer rates is necessary before any advantage can be obtained in the design of thermal protection systems for hypersonic vehicles.

2. Justification for Test on the Research Vehicle

Ground test plasma arc facilities can be used only to provide a limited understanding of these phenomena because they cannot simulate all of the significant flight parameters.

Substantial results could be obtained from scale model test flights of the unmanned PRIME type. However, as the vehicle size is greatly reduced, the accuracy of the measured data is degraded.

3. Crew Tasks During Experiment

Monitor test data.

RESEARCH TASK DEFINITION

TASK TITLE	
Catalytic Wall Experiments	TASK NO. SM-16 RANKING 43

OBJECTIVE

To determine the effects of wall catalyticity on heat transfer rates.

DESCRIPTION

The catalytic efficiency of various materials will be reviewed and several materials suitable for coating the exposed surface of heat flux calorimeter will be selected for test evaluation. Detailed ground tests will be conducted in plasma arc facilities to define the phenomena and correlate analytical predictions. The most promising catalytic and noncatalytic materials will be selected for flight testing.

Several areas of the vehicle, where slow atom recombination rates are expected both in the boundary layer and at the surface, will be selected for locations for the heat flux gages. A catalytic calorimeter, a noncatalytic calorimeter and a pressure sensor will be utilized at each test location to obtain quantitative data. Suitable provisions will be made to prevent contamination of the calorimeters by deposits from ablative pyrolysis gases. During the flight the output of calorimeters and the pressure sensors will be monitored and recorded.

At the end of the flight test the data will be correlated with the ground test data and analytical theories to obtain a more complete understanding of the effects of all catalyticity on heat transfer rates. Studies will be made to determine the possible application of this phenomena in the development of more efficient radiative and ablative heat shields.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C or F	Min. 1 Max. 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Temperature	Thermocouple	24
Heat flux	Calorimeter	6
Pressure	Pressure transducer	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK SUMMARY

F. GENERAL STRUCTURAL	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
SM-17 Structural response and loading	X			X	X	X	X	X	X	X	X	X		X				X	X	
SM-18 In-flight heat shield repair		X		X	X	X	X	X	X	X	X		X	X		X			X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Ascent-Static and Dynamic Response and Design Criteria Determination	SM-17

1. Technology Status Assessment

The structural response of a lifting body-adapter-booster vehicle to the load and vibration environment through the launch phase is most important. This phase includes the critical design conditions for much of the spacecraft as well as the adapter and booster and encompasses the problem areas of gust loads, wind shears, fin flutter, buffet and acoustic environments. Analysis techniques for the solution of response modes are very limited in the buffet problem area and need improvement in the other areas. Final verification of predicted response based on wind tunnel test data and analysis can only be acquired by flight test. Flight test data can then be used to improve analysis techniques as well as to generate adequate design criteria.

The basic problem is to establish design criteria to properly predict and evaluate the load environment with the resulting structural response necessary to ensure structural integrity for lifting body applications.

2. Justification for Test on the Research Vehicle

The result of this research task is to establish design criteria and a method of analysis for lifting bodies verified by flight test measurements of environment and structural response. Future programs can then utilize these results in order to preclude further extensive flight test research, relying on tunnel testing and analysis.

3. Crew Tasks During Experiment

Since the major portion of this research task will be accomplished on the first unmanned flight, man's contribution is negligible.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. SM-17
Ascent-Static and Dynamic Response and Design Criteria Determination	RANKING 21

OBJECTIVE

To research environment and response for lifting body during ascent in order to establish design criteria and methods of analysis.

DESCRIPTION

Initially a state-of-the-art analysis is made to predict environment and response in order to arrive at a conservative structural design. Wind tunnel testing is then required using ICB techniques to verify and/or modify original analysis and design.

Prior to launch, winds aloft profiles shall be obtained in order to define the environment. Instrumentation to obtain accelerations, pressures, acoustic levels and loads shall be recorded from launch to booster engine cutoff.

Postflight analysis of data shall be used to correlate analysis, model test data, and flight test data. Evaluate vehicle response and establish a structural design criterion accordingly. Monitor subsequent flights for correlation to previous flight test data and predictions.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A is suitable	Min. 1 Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Acceleration	Accelerometer	30
Pressure	Pressure transducers	50
Acoustic intensity	Microphone	4
Strain	Strain gage	50
Monitor rate gyro outputs		
Ground		
Wind profiles	Sounding balloons prior to launch	Includes sensors on adapter and launch vehicle.

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
In-Flight Heat Shield Repair	SM-18

1. Technology Status Assessment

The necessity for in-flight repair of a heat shield could arise as a result of minor damage received during the launch phase, perhaps as a result of shroud or fairing separation or during the orbital phase, perhaps as a result of micrometeoroid impingement, accidental striking during a docking operation or while working on an adjacent surface. The resulting irregularity could well disturb aerodynamic characteristics and/or create localized hot spots or weak areas which could result in more extensive damage during entry, possibly endangering the crew or the mission. In-flight repair would permit normal entry procedures to be followed thus reducing the probability of mission abort and vehicle loss.

2. Justification for Test on the Research Vehicle

Prior to attempting in-flight repair, extensive ground testing will be required to establish procedures, tools and materials. However, the problem is composed of three aspects which, taken together, require that solution involve a lifting entry vehicle. Thus, the task must be accomplished during an orbital phase, performed by a man working outside the vehicle, and must be done on a vehicle which will undergo entry during which man is in control so that aerodynamic and heating constraints must be tolerable and conducive to safe vehicle return.

3. Crew Tasks During Experiment

Man is an integral part of problem solution. He determines the nature and extent of the damage, implements the repair procedures, and evaluates the quality of repair directly by inspection during orbit, indirectly by sensor reading or handling qualities during entry, and, finally, directly by observation and test after landing.

RESEARCH TASK DEFINITION

TASK TITLE	
In-Flight Heat Shield Repair	TASK NO. SM-18
	RANKING 51

OBJECTIVE

Evaluation of in-flight heat shield repair technique.

DESCRIPTION

Prior to attempting the repair procedure, it is assumed that astronaut mobility, ingress, regress, have been demonstrated, and that the necessary tools and materials have been developed. In general the procedure would involve:

(1) Astronaut dons extravehicular suit and gathers tools and camera.

(2) Astronaut leaves vehicle, attaches umbilical(s) as required, inspects vehicle exterior, locates area needing repair and photographs it.

(3) Following a prescribed procedure the damaged area is prepared, repair material mixed (probably in a special container) and then applied and smoothed into surface. After repair the area is photographed again; a motion picture or extensive still pictures of the repair procedure would be valuable.

(4) Astronaut(s) gather camera(s) and tools and return to vehicle cabin.

(5) After landing, the repaired area is inspected, tested, and compared to non-repaired regions; photographs of the repair procedure are evaluated to ensure adherence to prescribed procedure.

At least four manned flights in which flight controls are evaluated must be completed before attempting this experiment.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A and B is suitable	1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Visual observation and photographs of repaired area before and after repair and after landing	Cameras	

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
(1) Space opening, ingress, regress hatch (2) Extravehicular suit (3) Repair tools and equipment (4) Camera	WEIGHT (LB) 300 (136. kg) POWER (WATT) 0

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

G. HUMAN FACTORS	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
HF-1 Pilot control and landing of vehicle after prolonged zero-"g" environment	X			X				X		X	X			X		X			X	
HF-2 Obtain crew biomedical data throughout flight	X			X	X	X	X	X	X	X	X	X	X	X		X			X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Pilot Control and Landing of Vehicle After Prolonged Zero G Environment	HF-1

1. Technology Status Assessment

The basic question to be answered is whether or not a prolonged time in orbit results in degraded performance during deorbit, re-entry and landing of a lifting entry vehicle.

In the HL-10 vehicle, the pilot performs as an integrated component of the systems designed to control the vehicle during deorbit, re-entry and landing. Even under the best conditions, the pilot's tasks will be considerably more complex and will require greater precision than normally found in nonlifting vehicles. Under less than optimum conditions, the stresses imposed on the pilot might seriously degrade his performance capability. During the normal course of testing, i.e., on three-quarter orbit to 16-orbit missions, the pilot's capability to execute the required tasks under a variety of conditions will be demonstrated. In addition to these performance measures, data on the stresses to which the pilot is exposed, as well as his reaction to them,will be obtained.

Realization of the maximum potential of a lifting re-entry vehicle will require demonstration of the pilot's ability after a prolonged stay in space. For example, use of a vehicle on a crew rotation mission is most effective when an entire crew is exchanged, rather than using a special ferry pilot. With such a scheme, the return crew plays an active role rather than just going along for the ride. Prior to committing a crew to such a role, assurance that their physiological condition and performance capabilities had not been significantly degraded as a result of their time in orbit would be required.

2. Justification for Test on the Research Vehicle

Because the test involves use of a pilot with at least 30 days zero-g experience controlling a lifting entry vehicle immediately following his orbital experience, ground test and drop tests would be inappropriate. Of necessity a lifting entry vehicle is required.

3. Crew Tasks During Experiment

The test serves to validate the concept of complete crew exchange during a crew rotation/resupply mission, or the feasibility of orbital crew members piloting the entry vehicle for routine (or emergency) return. One pilot serves as the subject to be evaluated while controlling the vehicle, while other personnel are actively monitoring and evaluating performance.

RESEARCH TASK DEFINITION

TASK TITLE	
Pilot Control and Landing of Vehicle After Prolonged Zero G Environment	TASK NO. HF-1 RANKING 45

OBJECTIVE

Demonstrate pilot control during deorbit, entry, and landing after at least 30 day zero G experience.

DESCRIPTION

See attached sheet (page 72)

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A, B and S is suitable.	Min. 1 Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Voice communication	Tape recorder(s)	2
Electrocardiogram	Gemini-type electrocardiograph	4
Blood pressure	Gemini-type sphygmomanometer	2
Respiratory rate and tidal volume	Gemini-type pneumograph	4
Body temperature	Thermistor	4
Flight characteristics and performance measures	Control position and movement	

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
Vehicle docking and crew transfer capability or 30-day space stay systems capability.	WEIGHT (LB) +500(227 kg) POWER (WATT) 1000

DESCRIPTION

This task assumes that man in the loop simulation, drop testing, and normal vehicle tests have demonstrated the capability of the pilot to control and land the vehicle. Because we want to determine the effect of prolonged zero G experience independent of the possible effect that lack of practice might have,it will also be necessary to demonstrate what effect lack of practice might have. This could be done using samples of pilots, both trained to acceptable baseline performance and otherwise equated on relevant variables. One group would be maintained in a current status with opportunity for practice, e.g., flying aircraft, simulators, etc. The second group would not have practice opportunities other than those which would occur during routine orbital operations. At the end of the desired time period, i.e., 30 days, both groups would fly the re-entry and landing profile. Comparison of the adequacy of performance of the two groups would permit assessment of the effect of lack of practice. If lack of practice results in performance degradation, then provision for maintaining re-entry skills while in orbit must be made. If lack of practice does not result in performance degradation, we can proceed with the experiment to determine the possible effect of prolonged zero-g exposure.

Also assumed are a station in orbit with at least one crew member having been there 30 days and a rendezvous and crew transfer capability. The procedure to be followed is:

(1) Launch research vehicle, achieve proper orbit, rendezvous, and have exposed crew member enter into entry vehicle.

(2) Remain in orbit sufficiently long to hook up recording equipment and verify return procedures, briefing, "subject pilot" assumes command and proceeds to execute deorbit, entry, and landing procedures. During this time, the backup pilot monitors critical flight parameters and assesses adequacy of the subject pilot's performance. If performance is judged inadequate, the backup pilot has to take over command.

(3) Physiological and performance measures would be taken and recorded throughout. Telemetry does not appear essential.

(4) After landing, the various measures would be analyzed to determine the extent of correlation among the various variables.

Large weight increment and electrical power capabilities need to be added to the EV for this experiment to provide for crew transfer to acquire a subject pilot having prolonged exposure to zero-g.

At least five manned flights are to be completed before attempting this experiment.

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Crew Biomedical Monitoring	HF-2

1. Technology Status Assessment

Crew biomedical monitoring is an essential part of any program in which man will be exposed to a variety of stresses which may well have an effect on his safety, well being, and/or performance. Because all are dealing with a research vehicle performing research tasks in which man participates, it is important to identify possible relationships among the various physiological measures and their relation to performance or flight conditions.

2. Justification for Test on the Research Vehicle

Ground testing will serve to establish a baseline for evaluation purposes. Other orbital testing will supplement or be supplemented by the acquired data. Only in a lifting entry vehicle are the various stresses interacting with the skilled performance requirements. Therefore, the data must be gathered using a lifting entry vehicle.

3. Crew Tasks During Experiment

Man is the subject of the evaluation, his condition and his performance.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. HF-2
Crew Biomedical and Performance Monitoring	RANKING 36

OBJECTIVE

Evaluation of crew physiological condition and relation of this to flight conditions, stresses and overall performance.

DESCRIPTION

In-flight biomedical monitoring assumes that adequate sensors and recording devices have been developed and that baseline data have been established for each astronaut. Presently, it is planned to monitor and record voice communication, electrocardiogram, blood pressure, respiratory rate and tidal volume and body temperature. These would be monitored and recorded in real time throughout the launch, orbit, deorbit, entry and landing phases. Simultaneously, performance measures and flight parameter information would be recorded. The records would be analyzed after landing to determine the degree of relationship among the physiological, performance and flight variables. The simultaneous recording and analysis of physiological measures, performance measures (both flight and research related), and flight parameter information will be especially useful in evaluating the appropriateness and adequacy of the research scheduled for a given flight. These data will indicate the extent of crew loading, either underload or overload. In turn, this assessment will permit the establishment of new schedules which will maximize crew utilization. In the event the scheduled research is not accomplished, these measures either singly or in combination may serve to identify probable reasons. Telemetry appears desirable, but onboard display is probably not necessary.

FLIGHT CONDITIONS	NO. OF FLIGHTS
All manned flights	

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Voice communication	Tape recorder(s)	2
Electrocardiogram	Gemini-type electrocardiograph	4
Blood pressure	Gemini-type sphygmomanometer	2
Respiratory rate and tidal volume	Gemini-type pneumograph	4
Body temperature	Thermistor	4
Flight characteristics		
Performance measures	Control position and movement	

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Additional biomedical equipment	WEIGHT (LB): 20 (9.1 kg)
	POWER (WATT): 0

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

H. CONTROL AND PROPULSION SYSTEMS		Category			Missions								Phase				Man			Work Statement	
		Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
FC-4	Flight control system		X		X	X	X	X	X	X	X	X			X			X		X	
PP-1	Reaction jet impingement effects	X			X	X	X	X	X	X	X	X		X	X		X			X	
PP-2	Reaction jet vehicle boundary layer interaction			X	X	X	X	X	X	X	X	X			X		X			X	
PP-3	Landing assist propulsion	X			X	X	X	X	X	X	X	X			X		X			X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Flight Control Actuation Experiment	FC-4

1. Technology Status Assessment

Hydraulic powered servoactuators have been chosen as the baseline control system for trim and stability augmentation during re-entry. Hydraulic servoactuators are traditionally used for these functions because the output is exactly proportional and because of the high degree of developed state of the art. The disadvantage with hydraulics, however, is that the system is inherently inefficient and therefore imposes a battery weight penalty on the vehicle. This disadvantage, as well as the weight of the system itself, provides a reason to search for other means of controlling the trim and stability of the spacecraft.

Other means of achieving attitude control and stability include electromechanical servoactuators, reaction control systems, or combinations of both. Some electromechanical systems provide more efficient energy consumption and lighter system weight. Since the reaction control system is required for in-orbit maneuvers, extended use and capacity could be efficiently accomplished, providing an overall weight savings.

The problem associated with using these alternate means of control is the lack of knowledge of the minimum control requirements of the vehicle during re-entry and the compatibility of the control systems with the vehicle flight characteristics. The ability of electromechanical servoactuators to perform flight control functions has been tested in North American's F-100 simulator and simulated in the PRIME computer program. Results with both simulated and actual actuators show that the flight characteristics of the vehicles are comparable to those achieved using hydraulic servoactuators. Reaction control system stabilization has been used on the X-15 and was part of the Dyna-Soar control system.

2. Justification for Test on the Research Vehicle

It is necessary to test the various combinations of equipments in a vehicle which is re-entering and landing and flown by a man. This testing is required to verify the man-machine-flight relations which cannot be fully evaluated by models and simulators. Some of the problems which cannot be fully resolved by ground test and scale models are:

(1) Minimum control and stability rate and duty cycle requirements.

(2) Degree of proportionality required for minimum acceptable flight characteristics.

(3) Hypersonic buzz characteristics of the surface control system.

(4) Ability of the reaction control system to stabilize the vehicle during re-entry flight.

(5) Wear rate relationship of the control surface cove seal to surface duty cycle.

3. Crew Tasks During Experiment

Man's contribution to the flight test is his ability to detect problems and provide solutions and/or alternate steps on the spot. Man provides flexibility, versatility and scope not possible to attain with instrumentation and rigid automation. Furthermore, since man is to ultimately fly the vehicle, the control system's relationship to him as well as to the vehicle must be evaluated.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FC-4
Flight Control Actuation Experiment	RANKING 33

OBJECTIVE

Use of reaction control system for re-entry stability augmentation and evaluation of electromechanical surface controls.

DESCRIPTION

See page 81

This task should not be programmed on the same flight as task F-2 and must be preceded by at least four flights on which task FC-1 is programmed.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C or F	Min. 1 Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Control surface position	Signal transducers	10
Guidance error	Airborne guidance computer	3
Vehicle attitude	Airborne guidance computer	3
Vehicle rate	FCS rate gyros	3
RCS fire time and frequency	Solenoid valve signals	16
Hinge moment	Load cells	16
Component temperature	Thermocouples	20

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)
Modify basic hydraulic control system to electromechanical driven elevons	200 (90.7 kg)
	POWER (WATT)
	0

Flight Control System Experimental Test Plan

The following test plan is outlined for using the reaction control system for re-entry stability augmentation in combination with a hydraulically powered surface control system and with an electromechanically powered surface control system. Also, the ability of the electromechanical control system to perform both the trim and stability augmentation functions will be tested. All results are to be compared to characteristics obtained using a hydraulic control system for trim and stability.

Preflight Tests

(1) Computer simulation studies

(2) Vehicle simulator studies

(3) Life and environmental tests for the electromechanical system.

Flight Tests

(1) Flight stability

(2) Vehicle maneuverability

(3) Maximum rate control at maximum dynamic pressures and maximum surface hinge moment

(4) Hypersonic buzz

(5) Dead band size

(6) Cove seal wear rate.

Post-test Evaluations

(1) Stability of vehicle control

(2) Pilot input--control systems output characteristics

(3) Fuel and power consumption and comparison of system combinations for least energy use

(4) Equipment condition.

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Jet Impingement Effects and Analytical Correlation	PP-1

1. Technology Status Assessment

Lifting body vehicles being unsymmetrical the cross-coupling and vehicle velocity changes associated with these jet impingement effects must be considered. Each vehicle/propulsion combination will generally present a unique set of conditions to be analyzed. Sufficient testing of various jet/impingement surface combinations should be accomplished to confirm and/or update the validity of the present method for computing jet impingement effects.

Present techniques for computing these effects involve the following:

(1) Determine the properties of the jet exhaust at the nozzle exit (pressure, temperature, ratio of specific heats, Mach number and flow angle) using a thermochemistry digital computer program.

(2) Using the jet exhaust gas properties from the thermochemistry program as input to a 3-dimensional method of characteristics digital computer program, determine the exhaust plume characteristics out to the surfaces encompassed by the plume.

(3) Assuming Newtonian flow, compute the normal forces exerted on each affected surface using the plume characteristics at the intersection of the plume with the surface.

Preliminary analytical studies for typical lifting body vehicles have indicated the magnitude of the resultant forces can be approximately 25% of the basic jet thrust, with the direction of application dependent on the impinged surface orientation.

2. Justification for Test on the Research Vehicle

Much can and should be accomplished in ground test facilities to produce a more valid analytical technique for estimating the effects of jet impingement. However, the unsymmetrical arrangement of lifting body vehicles will result in crosscoupling effects which can be expected to affect the guidance and control, navigation and propulsive reaction control systems design and performance compatibilities. It is highly unlikely that a true scaling of vehicle geometry and mass distribution and rocket thrust-time characteristics can be accomplished for thrusting tests in vacuum chambers. It is also impractical to consider full scale tests in ground facilities at this time.

Flight tests of a full-scale vehicle should be accomplished to determine scale and actual special environment influence on jet impingement effects. Flight testing is considered to be warranted, as the impingement effects appear to be significantly influenced by the ambient pressure, with equivalent altitudes of 300 000 ft (91.4 km) and above required to be maintained during the firing periods of the jets.

3. Crew Task During Experiment

Man will be in the control loop for rendezvous and backup system functions in lifting body vehicle operations. It will therefore be necessary to demonstrate the compatibility between man and the reaction control system with the resultant cross-coupling included.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. PP-1
Jet Impingement Effects and Analytical Correlation	RANKING 41

OBJECTIVE To develop a means for realistically computing the magnitude and direction of the forces as well as the temperature developed on vehicle surfaces by the action of jet exhaust plumes impinging on vehicle surfaces.

DESCRIPTION

Present means of computing the temperature and forces acting on surfaces encompassed by jet exhaust plumes involves the use of a 3-dimensional method of characteristics solution to determine the plume characteristics at the intersection of the plume and vehicle structure. The resultant surface pressures and temperatures are computed from this characteristic data based on Newtonian flow assumption. This task will provide the means of checking the validity of the above described analytical method and/or determining applicable correction factors to update the analytical techniques.

(1) Construct model where slope of impingement surface may be varied relative to nozzle centerline, and various size and exit Mach number nozzles may be fitted.

(2) Conduct firing tests in vacuum chamber for range of impingement slope, nozzle sizes and nozzle exit Mach numbers.

(3) Update analytical program by incorporating applicable test results.

(4) Conduct full-scale flight tests to verify computed effects.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable (vacuum experiment).	Min. 1 Max. 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface slope		--
Pressure on fin surface	Pressure transducer	20
Temperature on fin surface	Thermocouple	20
Nozzle flow rate	Flowmeter	16
Chamber pressure (jet)	Pressure transducer	16
Chamber temperature (jet)	Thermocouple	16
Vehicle acceleration along 3 primary axes	Σ accelerometers	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)
	0
	POWER (WATT)
	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Jet Exhaust/Vehicle Boundary Layer Interactions	PP-2

1. Technology Status Assessment

In general, preliminary propulsion system analyses have considered the thrust contribution associated with any of the vehicle's rocket engines to be that of the undisturbed jet exhaust only. The effects on interactions between the vehicle boundary layer and jet exhausts on thrust level and direction of application, and on the vehicle boundary layer flow, have not been considered. Because of the unsymmetrical vehicle shape and significant angle of attack during the re-entry flight mode considered, the cross-coupling effects associated with resultant jet exhaust/vehicle boundary layer interactions must be determined.

Analytical techniques must be developed to permit realistic determinations of the effects of jet exhaust vehicle boundary layer interactions for the conditions associated with the early atmospheric re-entry period where reaction control system operation may be required to augment the aerodynamic control system.

2. Justification for Test on the Research Vehicle

Test data should be accumulated for jet exhaust/vehicle boundary interactions for a range of flight Mach numbers from 15 to 20 and altitudes from 200 000 to 400 000 ft (61. to 122. km). The data should be obtained for the maximum range of vehicle angles of attack associated with operation in the flight regime noted.

Scaled testing may be accomplished in the MHD tunnels (Wright-Patterson AFB and AEDC). Flight testing will be required using a full-scale vehicle to correlate scale data and to define the actual vehicle boundary layer flow characteristics.

3. Crew Tasks During Experiment

Man will be in the control loop during the atmospheric re-entry phase. A significant part of the final testing will be to determine reaction/guidance and control systems compatibility with man's abilities. Man will be able to conduct the required testing in considerably fewer flights than an unmanned test vehicle could, as he can monitor and adjust the test procedure during a test to obtain the maximum accumulation of significant data for each vehicle flight.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. PP-2
Jet Exhaust/Vehicle Boundary Layer Interactions	RANKING 37

OBJECTIVE To determine the effects of the interactions between rocket exhaust jets and vehicle boundary layer on applied thrust vector and local heating effects associated with resultant boundary layer flow changes.

DESCRIPTION

Interactions between rocket exhaust jets and vehicle boundary layer flow will vary with vehicle flight altitude and Mach number. The significance of and methods for computing the effects of these interactions require test data for the boundary layer conditions existing on a full-scale vehicle during the initial atmospheric re-entry period.

(1) Conduct ground facility tests to measure these effects using scale models in the new MHD tunnels (50 MW at WPAFB, 500 MW at AEDC).

(2) Conduct flight tests with full-scale vehicle to measure effects and man control compatibility for a range of flight conditions extending somewhat beyond those associated with final full aerodynamic take-over.

At least four flights on which Research Task FC-1 is programmed must be completed before attempting this experiment.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A is suitable.	Min. 1 Max. 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Pressure (thruster chamber)	Pressure transducers	16
Temperatures (thruster chamber)	Thermocouples	16
Vehicle accelerations (angular and linear along all three axes)	Accelerometers	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Landing Assist Propulsion	PP-3

1. Technology Status Assessment

Turbojet and rocket engine applications have either too high an engine weight and volume or too large a propellant requirement, respectively, to permit their use as landing assist propulsion devices for a go-around capability in the landing phase for lifting body vehicles. Engine concepts such as the air turborocket do appear to offer the means of obtaining the required thrust and impulse for reasonable weight and volume expenditure.

2. Justification for Test on the Research Vehicle

Over-design of the landing assist propulsion system cannot be tolerated as it represents a significant weight item to be carried through the whole mission, thereby influencing heat shield and all other energy absorbing or dispensing system weights. The landing assist propulsion/vehicle flight characteristics of the HL-10 must be determined, as for any aircraft, in actual flight test.

3. Crew Tasks During Experiment

The performance requirements for the landing assist propulsion system will be based on man's control capabilities of the HL-10; it is imperative that he be used in the evaluation tests of the system. As the actual landing will be man-(pilot)-controlled in the operational vehicles, the landing assist system will best be considered in the same sense as the aerodynamic control system.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. PP-3
Landing Assist Propulsion	RANKING 32

OBJECTIVE

Determine propulsion system performance and installation characteristics to provide for "instant L/D" or go-around for augmenting landing safety.

DESCRIPTION

Availability of an "instant L/D" and/or go-around capability for small weight and volume expenditure may be very desirable for lifting body vehicles. Engine concepts such as the air-turborocket appear to offer a means of achieving this capability.

(1) Determine preliminary installation requirements and performance characteristics of representative engine cycles for this application.

(2) Select most promising system(s) and conduct detailed analytical studies of performance and prepare installation drawings for HL-10 vehicle application (and test vehicle).

(3) Conduct scale model tests in subsonic wind tunnel to determine performance characteristics of integrated vehicle/propulsion system.

(4) Conduct flight tests (drop from B-52) to determine full-scale vehicle performance characteristics.

NOTE: This task requires development of a high thrust-to-weight ratio engine with low specific fuel consumption. The air turbo-rocket has such a potential and is used as a model for this task. A much heavier but currently available engine, the J-97 (GE-1) is depicted in conceptual drawing of Part VII, as a secondary approach.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A and B is suitable (subsonic experiment).	Min. 1 Max. 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Throttle position	Indicator	1
Fuel flow	Flowmeter	1
Fuel pressure	Pressure transducer	2
Thrust	Load cell	2
Vehicle altitude, attitude, velocity, rate of climb, and acceleration	Camera	-

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
(1) Engine (2) Propellant (3) Exhaust and inlet-duct assemblies	WEIGHT (LB) 150 (68. kg) POWER (WATT) 0

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

I. GENERAL SYSTEMS	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
EV-2 Evaluate reuse capability and refurbishment requirements		X		X	X	X	X	X	X						X			X	X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Evaluate Reuse Capability and Refurbishment Requirements	EV-2

1. Technology Status Assessment

One of the design goals for future manned operational systems is to be able to refly the vehicle with a minimum of cost and turn-around time. Ultimately, cost effectiveness analysis must be made to determine what parts are best to reuse and those that are to be refurbished. Some overall system design limitation and capabilities will result in constraints in this study. Currently, much of the data for such studies must be estimated or assumed, since historical data on such system operations is not available. Because of this lack of data and test results, much controversy exists on which is the best approach. Since the plans are to refly this vehicle, and since it would be the first manned space system so developed, an extensive amount of initial studies and data collection throughout the study should be conducted to provide data and logic for future manned space system application.

2. Justification for Test on the Research Vehicle

This test is justified on the basis that it will provide extensive data and experience that can be used to more cost effectively conduct future manned space flight systems.

3. Crew Task During Experiment

Man does not make a contribution to the test.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. EV-2
Evaluate Reuse Capability and Refurbishment Requirements	RANKING 11

OBJECTIVE

To obtain reuse and refurbishment requirements and data for future application to entry vehicle operations.

DESCRIPTION

During the development phases of the program, trade-off studies will be made to determine if each component of the entry vehicle systems would be reused or refurbished between flights. A monitoring system will be established to collect data on turn-around time, cost and problems encountered on items that are reused and those that are refurbished.

After the program, this data will be collected and evaluated to establish systems data on reuse and refurbishment cost, turn-around times and the validity of the early trade-off studies. Where possible, criteria and overall guide lines will be established for reuse and refurbishment trade-offs for future operational systems.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable.	All refurbished and reused flights

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Ground measurements only	No flight instrumentation planned	

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
	0	0

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

J. STABILITY AND CONTROL		Category			Missions								Phase				Man			Work Statement	
		Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
FM-3	Evaluate flying qualities	X			X	X	X	X	X	X	X	X			X		X			X	
FM-4	Measure control effectiveness	X			X	X	X	X	X	X	X	X			X			X		X	
FM-6	Measure entry stability and control at various cg locations	X			X	X	X	X	X	X	X	X			X		X			X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Evaluate Flying Qualities	FM-3

1. Technology Status Assessment

No manned lifting entry vehicle has yet been flown hypersonically. Flying qualities criteria are not developed and may be complex based on present simulations and analysis results. Aerodynamics, in particular the lateral-directional derivatives including control effectiveness, are significantly different from present aircraft. The pilot's ability to fly the entry is therefore not predictable. Drop test flights will provide much information to lend confidence to the orbital entry flying qualities, particularly in the more critical transonic speed regime. Nevertheless, flights at hypersonic speeds, both at high altitudes (400 000 ft) (122. km) and low (100 000 ft) (30.48 km), are required to examine and understand the HL-10 flight handling characteristics throughout its performance envelope. The results are a foundation on which other experiments are dependent, such as manual energy management and experiments with task loading on the pilot and crew.

2. Justification for Test on the Research Vehicle

Extensive use of pilot-in-the-loop six-degree-of-freedom simulations is mandatory as a reference for design of the flight controls and displays systems. The simulator is also an important facility for exploring criteria from postflight analysis. It is inadequate as a sole means of study because it lacks the real entry environment which interacts strongly with pilot's commands, and because it can only approximate the highly nonlinear aerodynamic character of the vehicle and its controls system.

Small scale flight tests are inadequate because they omit the essential element of this class of experiment, namely, the pilot.

3. Crew Tasks During Experiment

Activate, monitor and respond to instruments and displays

Direct flight path program

Control vehicle attitude on all axes

Select control system mode

Provide comments and flying qualities ratings

Source of physiological data including response times and task loading capabilities while in controls loop

Adjust stability augmentation system (autopilot) gains.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-3
Evaluate Flying Qualities	RANKING 3

OBJECTIVE

To measure pilot's capability to fly the EV, to obtain EV response to attitude and rate commands, and to evaluate and establish criteria for aerodynamic and SAS (autopilot) characteristics, displays and side stick controller.

DESCRIPTION

Instruments are installed to measure pilot inputs, vehicle response and crew display information. Pilot's comments, ratings and physiological data are recorded. Evaluation of dynamic response is obtained with various stability augmentation system (SAS) gains selected by crew. First flight requires crew only to maintain nominal vehicle attitude. Later flights add control tasks such as step input commands, vary SAS gains. The task then obtains detailed vehicle response data over ranges of angles of attack and dynamic pressures. Crew task loading tolerance is measured. Effects of prolonged zero-g may be identified in later flights consistent with secondary objectives. Analysis provides comparisons with six degree-of-freedom simulator results, bases for selecting optimal setting of SAS parameters, and criteria for allowable maneuvers on future flights. Aerodynamic stability coefficients are obtained. FC-1 and FC-4 are performed in conjunction with this experiment, at least on early flights.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A and B is suitable (include maneuvers and programmed control deflections, progressive increase in flight environment).	Min. 4 Max. 10

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Controls hinge moments	Load cells	16
Controls positions	Potentiometer	10
Surface pressures	Pressure transducer	20
Accelerations (linear and rotational)	Accelerometers	9
Angular rates	Rate gyros	6
Pilot and crew behavior		15
Voice	Tape recorder	1

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
	0	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Measure Control Effectiveness and Damping Derivatives	FM-4

1. Technology Status Assessment

The aerodynamic control surfaces on lifting entry vehicles are generally imbedded in a complex flow field induced by the forebody. On the lower surface the elevons are preceded by a body surface where shock-boundary layer interactions occur. On the upper surface the elevons, flaps and rudder are influenced by the strong body vortices which sweep upward and aft from the nose between the fins, and by shock waves originating at fin leading edges. These complex, viscous, rotational flow characteristics lead to control moments which are dependent on Mach number, Reynolds number, angles of attack, sideslip and control surface deflection. The control effectiveness and hinge moments are therefore not analytical, but must be based on test measurements. The results have a strong effect on aerodynamic description of flying qualities, maximum lift, angle of attack limitations and control system design. The magnitude of hinge moments affects control system weight significantly.

Results of the flight experiment are used to derive dynamic stability and damping derivatives of the vehicle. The aero damping is very small and has not been obtained successfully in tunnel tests. These aero coefficients are important in the study of stability, in particular analysis of emergencies such as the event of SAS malfunction.

2. Justification for Test on the Research Vehicle

Tunnel tests provide basic original design criteria and are indispensable. They lack full confidence because of scale effects and flight vehicle design attributes such as structural vibration interactions with the air flow. Damping derivatives have not been measured satisfactorily.

Analysis is not applicable because of complex nature of a flow. Best efforts so far are directed toward a basic understanding of wind tunnel test anomalies.

Ground facilities do not exist for full scale simulations of flight.

Scale model tests could provide substantial data. Some effects of scaling would not be completely covered, however (e.g., separation and shock interaction), so that full-scale tests are necessary.

3. Crew Tasks During Experiment

This experiment may be initiated on unmanned flights. Later flights, the crew participates as follows:

- Activate and monitor instrumentation and displays.
- Direct flight path program.
- Initiate control deflections.
- Provide comments and pilot ratings of effectiveness of controls.
- Decide on limits of angles of attack and sideslip and control deflections.
- Adjust SAS (autopilot) gains and leads.

RESEARCH TASK DEFINITION

TASK TITLE	
Measure Control Effectiveness and Damping Derivatives	TASK NO. FM-4
	RANKING :2 7

OBJECTIVE

To evaluate aerodynamic control effectiveness and damping derivatives for stability and control and flying qualities analysis, and to provide basis for transferring from reaction to aerodynamic controls.

DESCRIPTION

The entry vehicle is instrumented to obtain pilot inputs, autopilot inputs and outputs, control deflections, hinge moments, vehicle response, and display information. The controls are actuated to induce deviations from trim conditions using various amplitudes and rates. Dynamic response is obtained with various SAS gains (including no SAS). Experiment is initiated out-of-atmosphere to evaluate RCS effectiveness and interactions. Duty cycles of both RCS and aero controls are measured. Vehicle data provides control effectiveness as functions of angle of attack and deflection. Interactions between rudder and elevon controls, and between pitch, roll and yaw axes are identified. Comparisons with wind tunnel data are made to substantiate ground tests. Pilot comments and ratings establish bases for flying qualities criteria in addition to those of Task FM-3. Repeat tests at higher dynamic pressures.

This task is to be programmed in conjunction with Research Task FM-3 and must be preceded by three flights in which FM-3 is conducted.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A and B is suitable (progressive increase in flight environment).	Min 2 Max 4

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Controls hinge moments	Load cells	16
Controls positions	Potentiometer	10
Surface pressures	Pressure transducer	20
Accelerations (linear and rotational)	Accelerometer	9
Roll, pitch, yaw rates	Rate gyros	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
	0	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Measure Entry Stability and Control at Various CG Locations	FM-6

1. Technology Status Assessment

Flying qualities and control effectiveness depend on cg location. Calculations can establish approximate aerodynamic limits within which the cg must lie. These limits are approached in flight test to demonstrate the vehicle controllability. The results are important in establishing ballast requirements and limitations in angles of attack and sideslip. This task is an extension of FM-3.

2. Justification for Test on the Research Vehicle

Wind tunnel test data is used to establish basic estimates of aerodynamic moments for any cg location.

Analysis includes stability analysis based on estimated aerodynamics.

Scale model tests are inadequate because of size effects on aerodynamics.

3. Crew Tasks During Experiment

Activate and monitor instrumentation and displays

Direct flight path program

Provide comments on flying qualities

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-6
Measure Entry Stability and Control at Various CG Locations	RANKING 26

OBJECTIVE

To demonstrate flying qualities and obtain criteria for allowable cg variations.

DESCRIPTION

Initial flights are assumed to have established suitable flying qualities with nominal cg constraints. Analysis then provides estimated limits for this test. The cg is located farther forward on first flight and farther aft on second flight, using ballast if necessary. Each flight includes evaluating aerodynamic stability and control characteristics.

This task must be preceded by three flights in which Research Task FM-3 is conducted.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C or F	Min. 2 Max. 4

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface pressures	Pressure transducers	20
Accelerometers	Accelerometers	9
Controls hinge moments	Load cells	16
Controls surface positions	Potentiometers	10
Vehicle rates	Rate gyros	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Ballast	WEIGHT (LB): 250 (113 kg) POWER (WATT): 0

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

	K. AERO-THERMODYNAMICS	Category			Missions								Phase				Man			Work Statement	
		Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
FM-7	Measure pressure distribution	X			X	X	X	X	X	X	X	X			X				X	X	
FM-8	Measure heat rate distribution	X			X	X	X	X	X	X	X	X			X				X	X	
FM-9	Measure gas cap radiation heat transfer		X								X	X			X				X		X
FM-12	Boundary layer survey			X	X	X	X	X	X	X	X	X			X			X		X	
FM-15	Measure plasma thermophysics	X			X	X	X	X	X	X	X	X			X				X	X	
FM-16	Effects of electrophilic fluid injection		X		X	X	X	X	X	X	X	X			X			X		X	
FM-17	Hypersonic boundary layer transition	X			X	X	X	X	X	X	X	X			X			X		X	
FM-18	Use of ventral antenna to alleviate communication blackout		X		X	X	X	X	X	X	X	X			X			X		X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Measure Pressure Distributions Over Entry Vehicle Surface	FM-7

1. Technology Status Assessment

Pressure distributions are required to evaluate airloads criteria and analyze heat transfer rates. They are used to provide understanding of aerodynamic characteristics, including basic flow features and boundary layer and shock layer phenomena. Some pressures are used as part of the air data system to derive angles of attack and sideslip. Pressure data is required on early flights for analysis of design margins. Results can affect local structure and heat protection design. The data will be obtained over the entire speed regime for comparison with wind tunnel test and drop test data.

2. Justification for Test on the Research Vehicle

Wind tunnel pressure tests are normally performed at all Mach numbers to provide basic design loads criteria. Tunnel tests, however, do not fully reproduce flight vehicle surface features and flight environment. Among the few flight tests for comparison are those of the ASSET and PRIME programs, which are different aero geometries.

Analysis techniques, such as Newtonian approximations, are not adequate for predicting pressures over the entire vehicle. Continued improvement of analysis depends, in part, on flight test comparisons.

Scale model tests can provide basic pressure information. PRIME experience, however, indicates a small size will result in a restriction on number of allowable pressure transducers. Model also does not provide full data in areas sensitive to size. Flight tests with full-size vehicle are therefore necessary.

3. Crew Tasks During Experiment

None.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-7
Measure Pressure Distribution Over Entry Vehicle Surface	RANKING 5

OBJECTIVE

To establish complete pressure distribution for use in analyzing air loads, heat transfer, aerodynamic flow field, and to obtain angles of attack and sideslip.

DESCRIPTION

Pressure instrumentation is installed over the entire entry vehicle, including fins, control surfaces and canopy for data acquisition throughout entry. In initial flights, angles of attack and sideslip are carefully controlled to obtain reference calibration pressure data at hypersonic speeds at low ablation, high ablation and after ablation; repeat data recording during descent at Mach 10, Mach 6, Mach 4 and Mach 2 for correlation with wind tunnel test and drop test data. Later flights obtain data at other Reynolds numbers.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C (Enter at $C_{L_{max}}$, modulate angle of attack in 2 steps. Later flights introduce sideslip angle.)	Min. 2 Max. 6
Type B (Same comment as above.)	1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface pressure	Pressure transducer	150
Controls positions	Potentiometer	10

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Measure Heat Rate Distributions	FM-8

1. Technology Status Assessment

Over a third of the entry vehicle weight is allocated to the heat protection materials. Their design is based on estimated heat transfer rates and integrated total heating. The rates are obtained at various stations over the body from analysis of wind tunnel test data and trajectory characteristics. The total heating is based on trajectory calculations for specific entry conditions and flight path control. These methods are complex and under continual revision as more is learned about air flow characteristics from analysis, flight and wind tunnel tests. Particular questions are whether or not the flow is in chemical equilibrium and the tendency toward turbulent boundary layer heat rates. High margins are applied to flap heating rates. Upper surface and base heating is small but not predictable. There is essentially no available flight data on lifting vehicles to provide comparisons. Present design practice is to estimate heat rates for both laminar and turbulent flow based on state-of-art analysis techniques, to make apparently conservative assumptions with respect to transition to turbulence, and to apply safety factors to heat shield design. The flight tests are important to confirm and amend heat rate estimates, to provide bases for improving analysis and to permit reducing tolerances on design criteria if possible. Results will be a better specification of vehicle flight capabilities and possible reduction in heat shield weights.

2. Justification for Test on the Research Vehicle

Wind tunnel tests provide basic laminar hypersonic heat transfer. Methods for establishing turbulent flow are not yet developed. Effects of scale and surface condition are not known.

Analysis in combination with wind tunnel tests and available flight tests (e.g., ASSET) are necessary to provide heat rate estimates. The methods are mainly empirical, and therefore dependent on test data for extrapolation and confirmation.

Ground test facilities can only satisfactorily provide laminar heating rates on small scale models, and have an unknown precision because of rarity of significant flight data at hypersonic speeds.

Considerable improvements in technology for providing heat rate criteria can be obtained with scaled-down vehicle tests. Scale limitations, however, include unknown size surface condition effects, number of allowable sensors, and later extrapolation to full size required. Small sizes also need to be designed for greater heating because the stagnation heat rates increase with decreasing leading edge radius. The question of transition is not resolved by a scale model test. Full-scale flight tests are therefore necessary.

3. Crew Tasks During Experiment

Experiment may be performed automatically. If crew is available, can assist as follows:

Activate and monitor instrumentation.

Manually trim to desired angles of attack and sideslip

Observe heating constraints on attitude and elevon deflections and adjust angle of attack.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-8
Measure Heat Transfer Rate Distribution	RANKING 2

OBJECTIVE

To obtain heat transfer rates in hypersonic flight over the entire vehicle.

DESCRIPTION

Heat transfer is dependent on many aerodynamic parameters including Mach number, Reynolds number, wall temperature, surface roughness and state of external air. The flight measurements will include heat flux, wall temperature and temperature gradients at selected points on leading edges and vehicle surfaces. The contribution of radiation heat transfer will be measured in a separate flight experiment, and will be significant on later flights at higher entry speeds. Simultaneous surface pressures are measured for analytic correlations and analysis.

This task must be programmed on flight with Task FM-7 (Pressure Distribution).

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C or F (Enter at $C_{L_{max}}$, modulate angle of attack in 2 steps. Later flights introduce sideslip angle.)	Min. 2 Max. 6
Type B (Same comment as above.)	1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Skin temperatures	Thermocouple	150
Heat flux	Calorimeter	150
Temperature gradients	Thermocouple	10
Attitude and rates		
Tracking		
Extend camera on boom for photographic coverage of state of outside surface prior to entry		

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
Camera and boom	20 (9.1 kg)	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Measure Gas Cap Radiation Heat Transfer	FM-9

1. Technology Status Assessment

Radiation heat transfer during entry has been under study for several years because of its importance in lunar and planetary return entries. Radiation properties of air therefore are well known for application to entry speeds (35 000 to 70 000 fps) (10.7 to 21.4 km/sec) associated with return from planetary missions using ballistic type vehicles. The aerodynamic flow characteristics are the unknown factors, requiring flight test confirmation of their effects. The design of the heat shield for supercircular entry up to 34 000 fps (10.4 km/sec) can be based essentially on convective heating rates. Above 30 000 fps (9.1 km/sec), however, the radiant intensity becomes large enough that measurements of radiation heat transfer are feasible. These results can be compared with predictions, and the postflight analysis can then provide extrapolations to higher speed entries with more confidence. The heat protection system of an operational vehicle may, therefore, be lighter because less design margin may be needed.

2. Justification for Test on the Research Vehicle

Wind tunnel tests (shock tubes) can provide some bases for generating design criteria but tests are limited to small models and short test times. Effects of ablation products in intensifying or subduing radiation cannot be measured. The results are therefore inadequate for mission design criteria.

Analysis methods based on available test data and techniques are crudely approximate. It is necessary to continue to develop analytic methods, in particular with application to lifting vehicle geometries.

Ground facilities do not exist for appropriate environment and size.

Small scale flight tests provide additional insight and valuable data for comparison with predictions. Scale effects such as radiant intensity increasing directly with leading edge radius make full size test desirable. Limitations on allowable instrumentation also compromise value of small size.

This test is not needed to meet primary research objectives, but is important for the supercircular entry secondary objectives.

3. Crew Tasks During Experiment

None

RESEARCH TASK DEFINITION

TASK TITLE	
Measure Gas Cap Radiation Heat Transfer	TASK NO. FM-9
	RANKING 48

OBJECTIVE

To determine magnitude of radiation of air in the shock layer from the nose region, and to evaluate effects of boundary-layer contaminants on radiation intensity. (This task is a part of a secondary objective.)

DESCRIPTION

The nose cap and forward sections of the leading edges and lower surface are instrumented to measure the air radiation contribution to heat transfer. Entry is made at a velocity of 30 000 fps (9.1 km/sec) or greater to achieve peak radiation heating rates of about 2 Btu/ft^2-sec (22.7 kW/m^2) or more. Radiation intensity and spectral distribution of energy is measured using radiometers, spectrometers, and thermocouples enclosed in transparent cases. The combined convective and radiative rates are also measured during entry; nose and leading edge ablation rates are determined. Analysis provides the relative intensity of radiation, the effect of contaminants (ablation products) and the spectral distribution of radiation for comparison with expected values.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type J (Pitch and roll modulation)	Max. 2, Min. 1
Type K (Pitch and roll modulation)	Max. 2, Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Radiation heat flux	Radiometers	6
Spectral intensity	Spectrometer	1
Radiation temperature	Thermocouples	20

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)
Radiometers and spectrometer	(11.3 kg) 25
	POWER (WATT) 100

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Boundary Layer Survey	FM-12

1. Technology Status Assessment

The problems of extending knowledge of the boundary layer characteristics have been under intensive study since the beginning of the century. As flight extends to higher speeds and altitudes, new aerodynamic problems arise which are influenced by this surface flow. Scientific advances depend on experimental measurements in new regimes. The test results will provide for extending basic aerodynamic technology to a higher degree of comprehension.

This experiment represents an important objective for research and technology development. However, the probes (or sensors) required to obtain the data have not yet been developed, and require an essential breakthrough in instrumentation.

2. Justification for Test on the Research Vehicle

Ground tests and analysis support the test but cannot duplicate size effects and flow environment.

Small scale flight tests are not applicable because of the development of the boundary layer along the surface of the vehicle. Full scale flight tests are therefore needed.

3. Crew Tasks During Experiment

Operate experimental probes.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-12
Boundary Layer Survey	RANKING 28

OBJECTIVE

To obtain total pressure and total temperature profiles through the boundary layer.

DESCRIPTION

Use movable pressure and temperature probes (rakes) to obtain boundary-layer data at various locations along the body. These rakes are extended into the flow during the hypersonic entry. Flight speed and angle of attack are maintained for the time required to obtain steady-state data. Measurements are obtained at various angles of attack.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any flight condition except A, E, H or S is suitable.	Max. 3 Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Pressure profile	Rake	10
Temperature profile	Rake	10
Surface pressures	Pressure transducers	20
Surface temperatures	Thermocouples	20
Heat flux	Calorimeter	10

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Measure Plasma Thermophysics and Chemical Concentrations	FM-15

1. Technology Status Assessment

Physical and chemical characteristics of the plasma affect electromagnetic propagation (communication blackout), radar cross-section (radar tracking) and entry signature (vehicle classification by ground or satellite based detectors). The plasma is the result of high velocity air passing through a shock wave, thereby converting the kinetic energy into thermal energy. The high internal energies disassociate and ionize the air. When the protective heat shield is ablative, products of ablation can act as catalysts in the equilibration of the boundary layer and reduction in electron densities. Easily ionizable contaminants (sodium and potassium) inherent in the ablator will themselves ionize, resulting in electron densities 2 to 5 orders of magnitude higher than that of the equilibrium air alone. It is extremely difficult to achieve such effects in the laboratory because of the requirements for high enthalpy, velocity and model size limitations. Flight tests can provide valid data which will result in definition of operational capabilities and identify avenues of approach for controlling the plasma. This test is a foundation for other related plasma tests in subsequent flights. Measurements of the attenuation level provide diagnostic data for evaluating the status of the plasma.

2. Justification for Test on the Research Vehicle

Tunnel test procedures are not developed but are needed to provide design criteria and instrumentation (sensor) development.

Analysis is not developed to an extent to provide entry vehicle design information.

Ground test facilities are not available except in small (several cms) size.

Some experimentation is possible in small scale flight tests, but size severely limits amount of instrumentation allowed and precludes knowledge of full size characteristics. Smaller leading edges affect shock-layer thermal characteristics such as shock stand-off distance, shock curvature, and enthalpy and density behind shock. Full-scale flight tests are therefore necessary.

3. Crew Tasks During Experiment

None

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-15
Measure Plasma Thermophysics and Chemical Concentrations	RANKING 34

OBJECTIVE

To determine the density and energy levels of electrons in the boundary-layer and wake, measure molecular relaxation rate and chemical composition including ablation products for analyzing aerodynamic and communication blackout phenomena.

DESCRIPTION

Study of the physics and chemistry of the electron plasma layer by measurements at hypersonic speeds and high heating rates. Boundary-layer and wake regions will be studied. Data will include electron noise level, electrical conductivity, concentration of elements and their ions, dielectric constant of ablator and plasma and RF attenuation. Parameters to be varied include heat rate and angle of attack. Electrical conductivity is measured using pairs of probes with time varying electrical potential.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any flight condition except A, E, H or S is suitable. (Modulate roll to maintain desired heat rate and angle of attack)	Min. 2 Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface pressure	Pressure transducer	50
Skin temperature	Thermocouples	50
Heat flux	Calorimeter	20
RF noise	Radiometer	5
Electron density	Electrostatic and Langmuir probes	5
Boundry layer composition	Mass spectrometer	3
RF reflected power	Reflectometer	3

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Transmitters: 1 VHF, 1 X-Band, 1 C-Band Antennas: 3 VHF, 3 X-Band, 3 C-Band Bidirectional couplers: 2	WEIGHT (LB): 15 (6.8 kg) POWER (WATT): 40

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Effects of Electrophilic Fluid Injection	FM-16

1. Technology Status Assessment

During entry, high temperatures are developed in the shock layer which cause dissociation and ionization of the air and ablation products. The resultant electron densities vary between 10^{11} and 10^{15} electrons per cc. The resulting plasma sheath absorbs and reflects electromagnetic waves causing attenuation of communication signals. The blackout period may extend for 3 to 6 minutes for ballistic vehicles (Gemini), for 7 to 18 minutes for medium L/D vehicles (HL-10), and up to 45 minutes for high L/D vehicles (advanced lifting designs). Operationally, such long blackout periods are very undesirable because of communication needs during the entire entry to aid the pilot in navigation and landing site status, and to maintain an informed control over the flight. A proposal for alleviating blackout is to inject a fluid into the plasma which is ionized positive and therefore captures electrons to destroy the plasma. Although initial developments of this technique are to be undertaken with the aid of laboratory experiments, the reproduction of the flight environment is at best very difficult. Flight tests are therefore necessary to develop and to qualify the systems which may successfully inject such fluids.

2. Justification for Test on the Research Vehicle

Plasma arc tests are required during development phase to determine fluid properties, to develop experimental systems for use in the flight tests, and to provide bases for estimating flow rate requirements.

Analysis techniques are inadequate because there is no experimental basis nor sufficient technological understanding of the flow interactions. Analytic methods must be generated as part of the research phase.

Ground facilities are inadequate to match flight environments and have insufficient plasma size for more than backup research tests.

Scale models could be used for this entry experiment, although instrumentation might be limited by allowable weight, power and volume.

3. Crew Tasks During Experiment

Control flow rates of injectants.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-16
Effects of Electrophilic Fluid Injection	RANKING 46

OBJECTIVE

To determine effects of electrophilic fluid injection on electron density, boundary layer state and heat transfer to relieve communications blackout.

DESCRIPTION

Study of effects of fluid injection on rf attenuation by capturing plasma sheath electrons. Measure and record X-Band and VHF signals received at a number of ground stations from on-board transmitters. Continuous monitoring and recording is made of incident and reflected power level in the transmission line of each transmitter. Also measure thermodynamic properties of boundary layer before and during the injection to establish flow characteristics. The fluid injection also provides boundary layer cooling, and measurements of heat transfer characteristics provide data concerning amount of heat reduction. Vary types of injectants and flow rates to ascertain parametric effects. Determine effects, if any, of injectant on a aerodynamic characteristics such as inducing flow separation.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Types C, D, F or I (modulate roll to maintain desired heat rate and angle of attack).	Min. 2 Max. 8

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Transmitter power	RF power meter	6
Reflected power	Reflectometer	6
Injectant flow rate	Flowmeter	3
Skin temperature	Thermocouples	10
Surface pressure	Pressure transducers	10
Electron density	Electrostatic probes	5
Boundary layer composition	Mass spectrometer	3

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Transmitters: 1 VHF, 1 X-Band, 1 C-Band	(18.1 kg)40
Antennas: 1 VHF, 1 X-Band, 1 C-Band	POWER (WATT)
Fluid and ejection system	50

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Hypersonic Boundary Layer Transition	FM-17

1. Technology Status Assessment

The transition of boundary layer flow from laminar to turbulent character continues to be studied experimentally and anlaytically. As flight has entered new regimes of Mach and Reynolds numbers, and as new surface roughness and temperature parameters become involved, the criteria for transition have become more complex. For entry vehicles, the additional friction and convective heating occurring in turbulent flow impose important penalties on performance and heat protection weights. In particular, hypersonic criteria associated with blunt, swept leading edges and with ablative surfaces are not generally established. The criteria also are complicated by their dependency on angle of attack and wall temperature. It is important for the designer to have criteria in which confidence exists. Two approaches presently are considered for lifting entry design. The first is to apply what are agreed to be conservative criteria for transition, and if then indicated, to design for laminar conditions. The second is to design for turbulence with the view of providing a margin of safety for flight unknowns, and accepting the weight and cost penalties.

2. Justification for Test on the Research Vehicle

Wind tunnel tests and analysis are necessary to provide a foundation of understanding the flow around the flight vehicle configuration. It is difficult, however, to control tests, primarily because of scaling, and wall temperature and roughness differences, to provide transition. A major test problem is inducing turbulence using normal methods because of the large angles of attack of lifting entry vehicles. Therefore, ground tests and analysis remain very necessary to initial design and as an aid to interpreting flight data, but they are not conclusive.

Scale model tests also help, but cannot replace full-scale flight tests because the viscous flow differs with size. Some supporting data is obtainable with the drop test vehicle, but the temperature environment cannot be achieved. It is important, therefore, to test in flight at full scale.

3. Crew Tasks During Experiment

Control artificial transition mechanisms and flow rates

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-17
Hypersonic Boundary Layer Transition	RANKING 16

OBJECTIVE

To measure location of transition from laminar to turbulent flow on vehicle lower surface and attempt analytic correlations based on available (scanty) wind tunnel and flight test data.

DESCRIPTION

Measurements of heat transfer, surface noise, shear and pressure are made to obtain data indicating where transition occurs. Fourier analysis of return signals from radar aid in detecting transition. Data are obtained at various Reynolds numbers and angles of attack at hypersonic speeds during and after ablation. Effects of surface roughness may be extracted from the data obtained in flight. Later flights attempt inducing transition by flying at higher Reynolds Numbers and by artificial roughness and other boundary layer tripping devices. Primary objective is to obtain data pertinent to HL-10 design criteria; secondary object is to acquire insight into the boundary layer behavior and criteria for general design.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C or F (step angle of attack)	Min. 1 Max. 3
Type I (step angle of attack)	Min. 1 Max. 3

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Skin temperature	Thermocouples	40
Heat flow	Calorimeter	40
Shear (friction)	--	40
Noise in boundary layer	Microphone	20

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Use of Ventral Antenna to Alleviate Communication Blackout	FM-18

1. Technology Status Assessment

As discussed for FM-16, communication blackout may be a severe problem for operational lifting vehicles. A proposal for alleviating blackout is to extend antennas below the entry vehicle, through the plasma sheath of the shock layer, into a region of low electron density. The ventral on which the antennas are extended must be protected from the high heating rate environment and may have some effects on aerodynamics. It is necessary to have a flight test experiment to obtain ventral and aero design data and to measure RF signal attenuation using the ventral antenna.

2. Justification for Test on the Research Vehicle

Plasma arc tests provide initial design data for estimating electron densities in the plasma sheath. Hypersonic wind tunnel tests provide basis for aerodynamic design of ventral. These tests are insufficient for developing operational system because of their inability to represent the high speed, high enthalpy flight environment and the small model scales allowable.

Analysis can provide initial design criteria but cannot prove system effectiveness.

Ground facilities are inadequate to provide environment and scale.

Scale models can be used to provide ventral design effectiveness during entry although extrapolation to full scale will remain to be proved. It is expected that the ventral thickness could be a smaller percentage size on the full-scale vehicle because heating rates on leading edges are lower with large nose radii. The aerodynamic disturbance of the ventral might therefore be lessened, so full-scale tests are needed.

3. Crew Tasks During Experiment

Extend ventral and monitor heat rates and RF attenuation. Withdraw or jettison ventral in event of excessive heat rates or deterioration of aerodynamic attitude control.

RESEARCH TASK DEFINITION

TASK TITLE	
Use of Ventral Antenna to Alleviate Communication Blackout	TASK NO. FM-18
	RANKING 50

OBJECTIVE

To determine effectiveness of an antenna which is mounted on a strut extending below the shock layer on RF attenuation and hypersonic aerodynamics.

DESCRIPTION

During entry an antenna is extended on a ventral strut below the vehicle through the plasma sheath. The effects on RF attenuation and vehicle aerodynamics are measured. Heating rates on the antenna ventral are monitored, and the ventral is retracted or jettisoned if anomalistic heating occurs. Heat rates are also assured on the lower surface of the EV to determine local heating criteria. Control effectiveness is obtained to ascertain possible deleterious effects caused by aerodynamic flow interference of the ventral support. Several antenna locations are examined and their relative effectiveness is determined.

This task must be preceded by at least four flights on which Research Task FC-1 is programmed.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A is suitable.	1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Ventral temperature	Thermocouples	20
Local body temperature	Thermocouples	20
Surface recession	Breakwire-type recession gages	2
Strain	Strain gages	20

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
Ventral antenna support	WEIGHT (LB) 200 (90.7 kg)
	POWER (WATT) 0

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

L. AERODYNAMICS		Category			Missions								Phase				Man			Work Statement	
		Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
FM-2	Evaluate aerodynamic characteristics	X			X	X	X	X	X	X	X	X			X			X		X	
FM-5	Measure elevon-shock interaction	X			X	X	X	X	X	X	X	X			X				X	X	
FM-13	Ablation effects on hypersonic aerodynamics	X			X	X	X	X	X	X	X	X			X			X		X	
FM-14	Viscous effects on lift and drag	X			X	X	X	X	X	X	X	X			X			X		X	
FM-19	Synergetic maneuver simulation without thrust		X			X	X	X							X			X		X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Evaluate Aerodynamic Characteristics	FM-2

1. Technology Status Assessment

Evaluation of many configuration characteristics, such as flight performance, flying qualities, structural and heat shield criteria, depends on aerodynamic data. Relatively little experience has been achieved with analysis of lifting vehicle aerodynamics, and the design technology is largely dependent on wind tunnel test data. Flight data is scarce for such vehicles, so there is little to confirm and give confidence to the adequacy of wind tunnel test data and projections to the flight environment. The drop test programs will provide some data from subsonic to supersonic speeds, but are limited (a) by not including ablation surface condition including leading edge recession effects, (b) by not including hypersonic speeds and (c) by not including low Reynolds number environment.

Present design practice is to assume that wind tunnel test data provide the best available estimate of aerodynamics, and to apply tolerances to obtain estimates of performance flying qualities and design criteria. This results in a possibly too conservative (heavy) design and in a possibly too restrictive performance capability. The best full-scale flight definition of basic aerodynamics of the HL-10 is essential to understanding its performance potential and is a foundation on which other important experiments are derived.

2. Justification for Test on the Research Vehicle

Tunnel tests are important sources of basic data but have the limitations of not including all effects of geometric changes, scale, and Reynolds number.

Analysis alone is inadequate because of complex geometric configurations and non-linear aerodynamics. Attempts at correlation analyses have generally worked well applying simple Newtonian flow approximations at hypersonic speeds for inviscid characteristics, but flight confirmation is scarce. At lower speeds (below Mach 5) correlation analyses generally have not been successful.

Ground facilities do not exist for full-scale flight vehicle aerodynamics except at subsonic speeds. The subsonic facilities are extensively used in preflight and post-flight analyses.

Flight tests using a smaller scale vehicle would provide valuable data. Some important aspects which involve scaling, however, would not be covered (e.g., separation effects). A full-scale test vehicle is necessary to evaluate all air flow characteristics.

3. Crew Tasks During Experiment

Activate and monitor instrumentation and displays. Direct flight path program. Adjust trim to pitch, yaw and roll axes.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-2
Evaluate Aerodynamic Characteristics	RANKING 4

OBJECTIVE

To obtain in-flight measurements of aerodynamic force and moment coefficients for evaluating performance and trajectory capabilities of this vehicle; to obtain effects of ablator recession, thermal and aeroelastic distortions on aerodynamics.

DESCRIPTION

Precise control of trajectory and vehicle attitude is maintained during this entry. Static aerodynamic forces and moments are determined using measured values of attitude rates, angles of attack and sideslip, accelerations, speed, attitude, dynamic pressure and supporting data. Surface conditions are measured, in particular ablation recession and aeroelastic deformations. The EV is held at a specific attitude for 15 to 30 seconds while steady state data is recorded; 5 to 10 attitudes are set up in each of 4 to 6 flight phases. Pilot sets up attitude and monitors attitude, velocity, altitude, rates and energy management displays. Angles of attack are determined precisely (1/4°). Analysis uses computer, statistical techniques utilizing on-board data, tracking data and meteorological sounding data to deduce aerodynamic force and moment data. Postflight subsonic aero data are obtained in wind tunnel using this flight vehicle; results are compared with similar preflight test. Wind tunnel and flight test data are compared.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Types C, D or F (step angle of attack between $C_{L_{max.}}$ and $L/D_{max.}$, roll modulate for altitude control, maintain energy management. Later flights introduce sideslip.	Min. 2 Max. 6

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface pressures	Pressure transducers	20
Accelerations (linear and rotational)	Accelerometers	9
Roll, pitch, yaw rates	Rate gyros	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Measure Elevon Shock-Interaction Effects	FM-5

1. Technology Status Assessment

Control effectiveness is difficult to predict because, in part, boundary-layer shock interactions take place in the vicinity of the elevons. The present experiment has the objective of measuring data to provide a basic understanding of the interaction phenomenon in support of research and technology (extension of Task FM-4). Dynamic wind tunnel tests of elevon configurations at hypersonic speeds have shown a tendency to develop unsteady boundary layer and external flow and elevon oscillations. This hypersonic buzz results from flow separation ahead of the elevon. The oscillations seem to occur at the frequency of structural vibration of the elevon, and depend on angle of attack. In addition, the effects of ablation may induce separation. This interaction phenomenon affects control system actuator power requirements by causing large dynamic hinge moments, and it is therefore important to investigate during entry flight.

2. Justification for Test on the Research Vehicle

Tunnel tests are important sources of basic data, and tests of the HL-10 configuration are recommended. The tests, however, cannot fully simulate flight scale and flow effects.

Analysis techniques are not available because of the complex flow field and lack of understanding of separation and shock interaction phenomena.

Ground facilities do not exist for full-scale simulation of the possible dependency on size of the interaction of structure and flow field.

3. Crew Tasks During Experiment

None.

RESEARCH TASK DEFINITION

TASK TITLE	
Measure Elevon-Shock Interaction Effects	TASK NO. FM-5
	RANKING 10

OBJECTIVE

To evaluate longitudinal stability and control surface effectiveness as affected by transition, flow separation and other elevon-shock interactions.

DESCRIPTION

Flight vehicle is instrumented on lower, aft surface including elevons to obtain surface pressures, heat rates, boundary layer noise and vibration environment data. Entry is made at high angle of attack and negative elevon deflections. The elevon deflection is increased in 10-deg increments; steady-state data is obtained at each position. Perform prior to ablation and repeat during ablation. Tendency for elevon hypersonic buzz and loss of control effectiveness is monitored and may limit allowable positive elevon deflection. On a subsequent flight, attempt will be made to induce unsteady flow phenomena by putting in large elevon step deflection while at large angle of attack. Analysis provides shock attachment, flow separation and boundary layer effects attributed to elevon-shock interactions.

This task must be preceded by three flights in which Research Task FM-3 is conducted.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any flight condition except A is suitable (step angle of attack, roll modulated).	Max. 3 Min. 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Elevon surface pressures	Pressure transducers	20
Aft-body surface pressures	Pressure transducers	30
Surface temperatures	Thermocouples	20
Heat flux	Calorimeter	10
Forebody pressures	Pressure transducers	20
Boundary layer noise	Microphones	10

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Ablation Effects on Hypersonic Aerodynamics	FM-13

1. Technology Status Assessment

Ablation heat protection causes a mass flow of contaminants into the boundary layer flowing over the entry vehicle. The contaminants are a mixture of gases of elements and complex molecules. Their effusion into the boundary layer affects skin friction, transition to turbulence, and flow separation (effects on electron density and heat transfer are included in other research tasks). Also the surface of the ablation changes character from a smooth, virgin state to a rough, marred state. The effects of effusion and charring on the vehicle are to change the lift, drag, stability derivatives and control effectiveness. Ablation therefore affects maneuverability and controllability. Methods of interpretation of flight data need to be developed. It may not be immediately practical to identify ablation and viscous effects separately.

2. Justification for Test on the Research Vehicle

Tunnel tests using porous models with which controlled blowing simulates ablation have been proposed. The simulation is usually felt to be insufficient, however, so that there is no confidence in such test results. Flight tests are needed to support or develop such ground test techniques.

Analysis techniques are unsatisfactory because of the extreme complexity of the boundary layer flow and insufficient knowledge of the character of the products of ablation and their mixing with the flow.

Ground facilities do not exist for actually blowing air at hypersonic speeds and enthalpy levels over ablating surfaces to measure such ablation results directly.

Scale effects such as transition and separation must be avoided, so the experiment requires flight using a full size vehicle.

3. Crew Tasks During Experiment

Activate and monitor instrumentation and displays. Direct flight path program. Adjust trim to pitch, yaw and roll axes.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-13
Ablation Effects on Hypersonic Aerodynamics	RANKING 9

OBJECTIVE

To evaluate effects of ablation on hypersonic lift, drag, stability and control

DESCRIPTION

This task provides for a study of the effects of ablation products on aerodynamics caused by changing the boundary layer chemistry, by inducing transition, and by altering flow separation. Heat transfer, surface pressures and hinge moments are measured with ablation of known out-gassing rate and composition. Aerodynamic controls are exercised to determine control effectiveness and stability at various angles of attack and Reynolds numbers.

Entire lower surface and leading edges are fabricated from a known set of ablator materials. Obtain data during period of medium heating rates at α's near 26 deg, 40 deg and 50 deg. At each angle, vary elevon deflection to measure its effectiveness. Repeat with a lower trajectory holding an altitude producing high heat rates.

Analyze data to obtain aero and control coefficients as functions of heating rate and angles of attack.

This task must be conducted in conjunction with Research Task FM-2.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Types C, D or F (Step angle of attack between $C_{L_{max}}$ and L/D_{max}, roll modulate for altitude control, maintain energy management. Later flights introduce sideslip.)	Min. 2 Max. 6

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface recession	Breakwire-type recession gages	4
Heat flux	Calorimeter	105
Surface pressure	Pressure transducer	100
Noise level	Microphone	14
Strain	Strain gages	40

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Viscous Effects on Lift and Drag	FM-14

1. Technology Status Assessment

The entry range potential (maneuverability) of lifting entry vehicles depends directly on their hypersonic lift-to-drag ratio. The basic inviscid values of lift and drag are obtained by the designer based on many compromises such as between internal volume and slenderness ratio. These are modified drastically at high altitudes (low Reynolds numbers) by skin friction, which also depends on ablation and angle of attack. The HL-10, for example, has a maximum hypersonic inviscid L/D of 1.14. At 200 000 ft (61. km) altitude, this is reduced to approximately 1.11, and at 300 000 ft (91. km), to approximately 0.61. The magnitude of the viscous degradation of L/D is not known very well. Estimates are based on a few experimental and analytic correlations obtained with lifting configurations, in addition to a background of hypersonic tests and analysis on simple (flat plate and cone) shapes. If the error in the viscous effect is 25% on L and D (each), the crossrange is degraded by 5%. Present design practice is to estimate the viscous effects and to attribute a large tolerance for conservative flight performance (crossrange) guarantees. The methods of interpreting flight data to separate ablation and viscous effects must be developed.

2. Justification for Test on the Research Vehicle

Tunnel tests using both simple geometries (flat plates) and entry configurations (HL-10, SV-5) are useful for obtaining design data. Limitations are imposed by available ranges of Reynolds numbers at the necessary hypersonic speeds. Data at low Reynolds number is difficult to obtain because of the low forces acting on the model. Tolerances in wind tunnel test data therefore are often too large to confirm correlation analysis.

Analysis leads to various correlation parameters such as $M/\sqrt{Re}$ and $M^{0.618}/\sqrt{Re}$ depending on assumptions regarding wall temperature and flow properties. These correlations may appear confirmed by ground tests on medium Reynolds numbers, but the extrapolation to low Reynolds number is still subject to question. Ground facilities exist for test at some combinations of Mach and Reynolds number, and should be fully exploited. Nevertheless, flight tests are necessary for extension to very high altitude conditions.

Flight tests require accurate control, measure and evaluation of angles of attack and sideslip. It is necessary to perform the experiment on a full-scale vehicle.

3. Crew Tasks During Experiment

Activate and monitor instrumentation and displays. Direct flight path program. Adjust trim to pitch, yaw and roll axes.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-14
Viscous Effects on Lift and Drag	RANKING 19

OBJECTIVE

To determine correlation parameters for viscous corrections to lift and drag for improving re-entry maneuverability (performance).

DESCRIPTION

Study of skin friction effects on vehicle lift and drag at hypersonic speeds and high altitudes by analysis of tracking, on-board accelerations and attitudes. During entry and at various angles of attack, Mach number and Reynolds number, establish vehicle attitude, velocity and 3-axis components of acceleration with precision. Angles of attack and sideslip need to be controlled and measured accurately (1/4 deg). Also measure shear forces if an instrument is available. Obtain accurate tracking and meteorological data with the aid of sounding rockets. Perform postflight analyses using statistical processes to determine aerodynamic data and to separate the viscous effects. Comparisons with other flight and test data and with possible correlation parameters provide results to define viscous corrections for future flights.

This task must be conducted in conjunction with Research Task FM-2.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C (Maintain angle of attack.)	Min. 2 Max. 6

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface pressures	Pressure transducers	150
Shear (friction)	--	20
Heat gradient	Thermocouples	10
Skin temperatures	Thermocouples	100

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
	WEIGHT (LB): 0
	POWER (WATT): 0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Synergetic Maneuver Simulation Without Thrust	FM-19

1. Technology Status Assessment

The synergetic maneuver consists of performing an orbital plane change by entering the atmosphere and applying a combination of aerodynamic and propulsion forces. Orbit is then re-established. Unknowns in application of this concept include guidance precision and techniques, propulsion system operation and thrust vector control, and heat shield behavior subsequent to the synergetic exposure to high heating rates.

The research entry vehicle can be used without thrust to provide design data for the heat shield and guidance systems, and to provide a base for development of flight procedures. These tests provide an important basis for design of synergetic maneuvering, operational vehicles, and will help significantly to shorten development time.

2. Justification for Test on the Research Vehicle

Ground tests cannot reproduce the flight environment adequately, in particular the high vacuum orbital environment following the maneuver, and the high heating, acceleration and vibration environment during the maneuver.

Scale model flight tests can provide valuable data concerning heat shield and guidance system capabilities. They do not eliminate need for prototype development, however, because of unknown scale effects.

The drop-test vehicles, or other in-orbit vehicles, are not applicable.

3. Crew Tasks During Experiment

Direct flight programs and adjust for contingencies if necessary.

Correct navigation and guidance for maneuvering dispersions prior to final entry.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FM-19
Synergetic Maneuver Simulation Without Thrust	RANKING 52

OBJECTIVE

To evaluate heat shield and guidance system operations during and after an aerodynamic maneuver and subsequent exposure to high vacuum environment.

DESCRIPTION

Entry is begun without modulation of phugoid damping so that the entry vehicle will skip to high altitude after exposure to high heating and an aerodynamic turn. As an example, from 80/200-nautical mile (148/370 km) orbit, use $\Delta V = 100$ fps (30.5 m/s) for shallow entry (-1°). Enter with 60° bank angle at $L/D_{max.}$. When heading changes 2°, increase angle of attack to $C_{L_{max.}}$ and obtain zero bank. Allow entry vehicle to skip, and at next apogee apply ΔV for normal entry (-1.5°) into selected site. Instrumentation measures surface pressures, temperatures, heat flux, guidance parameters, navigation errors and display performance during entire flight. Near apogee, status of heat shield and thermal gradients are evaluated prior to entry. Later flights extend to longer duration heating and larger maneuvering. Requires heat shield and guidance modifications to meet criteria for maneuver.

At least four flights in which Research Task FC-1 is programmed must precede this task.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type S	Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Surface temperatures	Thermocouples	160
Heat flux	Calorimeters	150
Temperature gradients	Thermocouples	10
Surface recession	Breakwire-type recession gages	20

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
	WEIGHT (LB) 0
	POWER (WATT) 0

RESEARCH TASK SUMMARY

M. GUIDANCE AND NAVIGATION	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
GN-1 Primary navigation and guidance performance	X			X	X	X	X	X	X					X		X			X	
GN-2 Demonstrate backup guidance system performance	X			X	X	X	X	X	X					X		X			X	
GN-3 Autonomous orbital navigation		X		X	X	X	X	X	X				X	X			X		X	
GN-4 Inertial navigation error propagation		X		X	X	X	X	X	X			X		X				X	X	
GN-5 Hypersonic re-entry guidance techniques		X							X	X	X			X		X			X	
GN-6 Terminal navigation and guidance techniques	X			X	X	X	X	X	X	X	X			X			X		X	
GN-7 Air data measurements		X		X	X	X	X	X	X	X	X			X				X	X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Primary Navigation and Guidance Performance	GN-1

1. Technology Status Assessment

The criteria, upon which a baseline navigation and guidance subsystem design is based, stem from anticipated flight test requirements for the HL-10 research program. The baseline design goal is to realize maximum simplicity and reliability compatible with these criteria. However, by so doing, the design requirements for most potential near-earth orbital missions are also met. Consequently, significant research applicable to future operational missions can be accomplished, with no modifications to the baseline equipment aside from instrumentation provisions and operational procedures.

Subsequent paragraphs will review pertinent technology status relative to potential operational missions; navigation and guidance will be discussed separately for reasons that will become obvious.

Navigation

Navigation is the process of continuously determining three-axis position, velocity and attitude in a known reference frame.

The technology status of inertial navigation through the hypersonic phase of re-entry, as exemplified by Gemini flight results, indicates that no serious navigation problems should be encountered with a mid L/D vehicle re-entering from a logistics-type mission. However, the expected 3σ initial condition inaccuracies at deorbit, which are the major sources of navigation error propagation (refer to table 8 and ref. 7), are such that some form of terminal navigation updating will be necessary. This updating cannot be accomplished by pilot visual sightings from 100 000 ft (30.48 km) of altitude at about Mach 3, presuming perfect visibility; the vehicle maneuver capability from Mach 3 is not adequate to compensate for the navigation error buildup due to estimated 3σ initial condition perturbations listed in table 8. Note in table 8 that inertial navigating errors increase with re-entry flight time, and therefore with larger initial velocities and/or L/D ratios. Should initial condition inaccuracies for a mid L/D vehicle approach the table 8 values or terminal visibility be poor, reliance must be placed on terminal navigation updating. A precision tracking radar at the landing site plus a communication link could correct trajectory dispersions of five times those in table 8 for a medium L/D vehicle. (This terminal radar is an integral part of the recommended baseline concept, and it provides a high probability of normal recovery at the primary landing site even with the backup airborne guidance system.) Thus the navigation problem reduces to how many ground tracking nets are required for each mission. The acceptable solution is that no more than one be required for each landing site, whereas the desired solution is none.

Guidance

Guidance is the process of energy management or maneuvering the vehicle (e.g., by angle of attack and bank angle modulation) to reach the desired landing site in accordance with navigation data, while staying within specified vehicle constraints such as temperature, airloads and L/D control range. The guidance commands of angle of attack (α)

TABLE 8

INERTIAL NAVIGATION ERRORS AT TERMINAL RADAR ACQUISITION

Error source (3 σ estimate)	L/D = 1.0 nominal Along range naut mi	(km)	L/D = 1.0 nominal Crossrange naut mi	(km)	L/D = 3.2 nominal Along range naut mi	(km)	L/D = 3.2 nominal Crossrange naut mi	(km)
$\Delta\phi = 0.3°$	--		5.0	(9.3)	--		36.0	(66.7)
$\Delta\psi = 0.3°$	--		5.0	(9.3)	--		28.5	(52.8)
$\Delta\theta = 0.3°$	5.0	(9.3)	--		36.0	(66.7)	--	
Δh = 10 fps (3.05 m/sec)	0.8	(1.48)	--		36.0	(66.7)	--	
$\Delta x_i = \Delta \dot{y}_i$ = 10 fps (3.05 m/sec)	1.6	(2.96)	1.6	(2.96)	3.0	(5.56)	3.0	(5.56)
$\Delta x = \Delta y$ = 6.0 naut mi (11.1 km)	6.0	(11.1)	6.0	(11.1)	6.0	(11.1)	6.0	(11.1)
RSS TOTAL	8.0	(14.8)	9.4	(17.4)	51.4	(95.2)	46.4	(85.9)

NOTE: Initial attitude reference by horizon tracking plus gyro compassing and bank angle (ϕ) can be computed automatically, or determined by the pilot based on displayed navigation data plus constraints. Also, the guidance commands can be executed automatically via the electronic flight control system (FCS), or manually via control stick inputs to the electronic (fly-by-wire) FCS. In contrast, inertial navigation computations must be done automatically.

Guidance technology status through the hypersonic phase of entry is based on limited flight results of the Gemini program, plus copious computer simulations of low and medium L/D re-entries. These simulation results for Gemini, Apollo, Dyna-Soar, PRIME, etc., substantiate that automatic execution of the guidance function will introduce no more than a mile or two of dispersion through hypersonic flight. This is considerably less than the table 8 autonomous inertial navigation error propagation. The hypersonic guidance problem thus reduces to how much man will contribute (e.g., by constraint monitoring and control during abort and malfunction situations plus selection of an alternate landing site), or degrade performance (e.g., by sporadic control inputs which may also drain the power supply). Display provisions are especially important and unresolved. Arriving at a near optimum solution requires extensive man-in-the-loop simulations plus flight testing.

Guidance technology status from Mach 3 to tangential landing is based almost solely on X-15 flight test experience. Computer simulation results for approach and tangential landing of medium L/D vehicles are extremely limited. In this flight regime, guidance performance must be more precise and faster. Moreover, vehicle maneuverability during transonic flight may be limited by dynamic stability constraints on α. A major problem area is the performance adequacy, for a limited visibility landing approach, without a go-around cruise engine or an instant L/D engine for landing assist. This adequacy also depends upon the drag brake control range available for landing assist. This performance adequacy can only be verified by extensive computer simulations plus flight testing of simulated all-weather landings. It is noteworthy that limited computer simulation results of guided SV-5 vehicle flights from Mach 3 to flare initiation indicate satisfactory performance. Table 9 lists perturbation dispersions from nominal, for ground radar controlled simulations without thrust or drag brake control.

2. Justification for Test on the Research Vehicle

It can be argued, and rightly so, that hypersonic guidance concepts and inertial navigation error propagation can be sufficiently well evaluated by ground simulation to select an adequate (and nearly optimum) approach for a medium L/D vehicle entering from any low earth-orbital mission. The recommended baseline concept hopefully represents exactly this approach, but it is recognized that flight evaluation--particularly with pilot in the loop--is needed to verify and refine the chosen baseline concept.

With regard to the need for flight testing of the terminal navigation and guidance modes, ground simulations of terminal guidance are inadequate to evaluate pilot control under visual conditions, but are quite valid for the design verifica-

TABLE 9

DISPERSIONS AT FLARE INITIATION ALTITUDE

Off nominal condition	Terminal dispersions at h = 670 ft (204 m)						
	Velocity, V		Range, R		Flight path angle, γ,	Crossrange, XR	
	fps	(m/sec)	ft	(m)	deg	ft	(m)
ΔR_i = 7 naut mi (13 km); XR_i = 17 naut mi (31.5 km)	-25	(-7.62)	-300	(-91.4)	0.8	105	(32.)
ΔR_i = -7 naut mi (-13 km); XR_i = -17 naut mi (-31 km)	0	(0)	-30	(-9.14)	0.0	280	(85.3)
50-fps (15.24 m/s) tailwind	70	(21.3)	6	(1.83)	-0.1		
50-fps (15.24 m/s) headwind	-82	(-25.)	-231	(-70.4)	-0.3		
50-fps (15.24 m/s) headwind and ΔR_i = 10 naut mi (18.52 km)	-153	(-46.6)	-2030	(-618.7)	-1.0		
Δh_i = -10,000 ft (3.05 km)	0	(0)	-50	(-15.2)	0.0		
ΔC_L = 10%	-15	(-4.57)	-260	(-79.2)	-0.5		
$\Delta\rho$ = -20%	-20	(-6.10)	-448	(-136.6)	0.5		
$\Delta\rho$ = 20%	-43	(-13.1)	-25	(-7.62)	0.8		
α_ϵ = 4 deg	-34	(-10.4)	382	(116.4)	0.2		
α_ϵ = -4 deg	-17	(-5.18)	-1078	(-328.6)	-0.8		
180-deg turn	0	(0)	-194	(-59.1)	-0.3	62	(18.9)
Nominal initial conditions	3163	(964.1)	72.3 naut mi	(134. km)	-3.1	0	(0)
Nominal end conditions	449	(136.9)	0		-13.1	0	(0)

tion of an all weather automatic landing system. Such performance must be verified by actual flights, but this could to a great extent be done in the HL-10 drop test program. Such flight verification is tentatively planned with visual pilot control, using an HL-10 vehicle boosted to about Mach 2. However, all weather landing is not planned during the drop program, although it could be evaluated by voice commands to a "blinded" pilot based on ground radar data. Moreover, a significant phase of the problem, which involves programming vehicle α from the back side to the front side of the L/D versus α curve above Mach 2 plus the induced flight path oscillations and the initial condition perturbations, is not planned as part of the drop test program. Certain of the terminal navigation experiments are well suited to a drop test program, particularly measurement of vehicle position and velocity coordinates by ground or airborne radar. However, attitude accuracy is limited by the crude instrumentation now in the drop test vehicle. Finally, terminal radar acquisition and guidance from approximately Mach 8 cannot be done in the drop test program.

3. Crew Tasks During Experiment

During normal entries, the pilot's primary task in the manual guidance mode will be to execute α and ϕ commands based on his displays. For such entries, selection of the automatic guidance mode through the hypersonic flight phase could be selected to ease his task loading, with the pilot monitoring the relative performance of the primary and backup systems (using his optical periscope as a comparison norm).

For actual or simulated malfunction type entries, the pilot can provide additional navigation sensing through the critical initial skip. By modulating α and ϕ in accordance with sensed acceleration magnitude through the initial skip, he can compensate for, monitor or simplify the implicit guidance stored programs (both primary and backup). After the initial skip, the programs would be relied upon to generate α and ϕ commands.

For demonstration of maneuvering to an alternate landing site, the pilot would select the appropriate site whose coordinates would be inserted into the guidance computer. He would use present velocity and maneuverability displays to first ascertain the ability to reach the alternate site.

After initiation of terminal radar guidance updating, the pilot will execute the transmitted α and ϕ guidance commands either manually or by selecting the automatic mode. Part of the navigation monitoring below Mach 3 will consist of visual observations of the landing site. He has the option of disregarding ground commands and doing a conventional (visual) landing with the aid of displayed air data.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. GN-1
Primary Navigation and Guidance Performance	RANKING 12

OBJECTIVE

To evaluate the applicability of the baseline primary navigation and guidance subsystem to potential operational missions.

DESCRIPTION

See attached sheet (page 140)

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C	Max. 2, Min. 1
Type F	Max. 4, Min. 1
Type G	Max. 4, Min. 1

MEASUREMENTS REQUIRED See attached sheet (page 141)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
NONE	0	0

DESCRIPTION: GN-1

The baseline primary navigation and guidance subsystem consists of an airborne inertial navigator plus a ground-based terminal complex located at the intended landing site. The ground complex consists of a tracking radar, computer and command transmitter; it generates guidance commands of angle of attack and bank angle (α and ϕ) after vehicle track has been established. The navigation and guidance computations are mechanized in a common digital computer, both for airborne and ground-based guidance. The implicit guidance equations used to generate the α and ϕ commands, in both the airborne and ground computers, are based on a preprogrammed reference trajectory and are very similar.

Performance will be measured and evaluated with regard to:

(1) Error propagation of the airborne inertial navigation and guidance subsystem during the hypersonic phase of entry.

(2) Maximum guided crossrange maneuverability.

(3) Automatic versus semiautomatic and manual modes.

(4) Alternate landing site maneuver capability, by guiding to a fictitious landing site during the early entry phase and subsequently switching the Edwards AFB coordinates into the airborne digital computer.

(5) Terminal navigation and guidance modes.

MEASUREMENTS REQUIRED: GN-1

Parameter	Instrumentation	No. of Sensors
Position (three axes)	Primary inertial navigation and ground tracking	3 each
Velocity (three axes)	Primary inertial navigation and ground tracking	3 each
Acceleration (three axes)	Vehicle accelerometers	3
Attitude (three axes)	Primary inertial navigation	3
Command angle of attack	Primary inertial guidance system	1
Measured angle of attack	Primary IGS, air data, ground computer	3
Command bank angle	Primary IGS computer and ground computer	3
Error signals to FCS, automatic mode (three axes)	Primary IGS computer	3
Pilot control stick signals	Pilot hand controller	3
Pilot α bias command	Input to primary IGS computer	1
Ground guidance command (α and ϕ)	Airborne receiver and decoder	2
Ground navigation inputs	Airborne receiver and decoder	6
Time after deorbit	Airborne and ground based timer	1 each
Horizon scanner signals in orbit	Dual horizon scanners	2 each
Diagnostics	Primary IGS, pilot displays, electronic FCS, rate gyros, control actuation, communication, etc.	100 +

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Backup Guidance Performance	GN-2

1. Technology Status Assessment

Backup guidance system design criteria include, in addition to using simplified and proven techniques, two important postulates. These are:

(1) The primary and backup guidance logic be compatible, so that the backup system could take over during entry should the primary system fail--e.g., at the bottom of the initial dip.

(2) The backup system be sufficiently accurate to enable normal landing at the primary landing site, with aid from ground equipment located only at the landing site.

PRIME simulation results verify that the second postulate can be attained using a simple implicit guidance scheme that preprograms the integral of body fixed acceleration and roll angle versus time. The first postulate is achieved by using an implicit law similar to the primary guidance system, which preprograms velocity magnitude and heading (or bank angle) versus range-to-go.

Analysis and simulation results to date indicate comparable accuracy for the primary and backup systems, assuming the major error sources to be initial condition errors at orbit departure (see table 8). The major limitations (potential problem areas), relative to using the backup guidance system for manned operational missions, are that it is not suitable for selection of an alternate landing site during the early phase of entry, for backup guidance during ascent, nor to generating α or ϕ commands during entry after a launch abort. Also, its display provisions are penalized (because three-axis position and velocity are not computed), gross time deviations from the stored nominal trajectory cannot be tolerated, and its growth potential is restricted (since one terminal guidance radar would be necessary even with perfect initial conditions and zero gyro drift). However, its simplicity and excellent performance, when used with a terminal tracking radar and up to 10σ initial condition dispersions from nominal, warrant its evaluation as backup for manned operational missions, and as the primary guidance system for unmanned missions.

2. Justification for Test on the Research Vehicle

The accuracy capability depends upon control system and piloting performance, since crossrange position errors are not measured and corrected as with the primary system. PRIME flights will verify unmanned performance of the scheme in the SV-5 vehicle, but piloting capability with the HL-10 control system must be demonstrated in flight. Ground simulations are a necessary prerequisite.

3. Crew Tasks During Experiment

Very significant, particularly if the pilot flies the displayed α and ϕ guidance commands. He can select automatic guidance; this is recommended to enable his attention to other tasks, such as continuously monitoring and comparing displayed data from the airborne primary and backup guidance systems plus ground up-data.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. GN-2
Backup Guidance Performance	RANKING 20

OBJECTIVE

To demonstrate the applicability of a re-entry backup guidance system to potential operational missions.

DESCRIPTION

The backup airborne guidance system consists of body fixed gyros and accelerometers, a programmer-computer and a precision power supply. The implicit guidance scheme makes use of reference trajectory parameters preprogrammed as a function of time. This program can be updated just prior to deorbit.

After verification of the primary navigation and guidance system (Task GN-1), during which flights the backup guidance commands have been recorded for comparative evaluation, the pilot will execute the backup guidance ϕ and α commands through hypersonic flight, or until ground based update commands are recieved. The backup guidance commands (and pilot response lags or errors) will be recorded for comparison with the primary guidance commands, and the primary system data will be compared to various signals within the backup guidance computer-programmer. Terminal radar tracking data will be the norm for evaluating relative performance of the primary and backup airborne systems.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C or F	Max. 2 Min. 1

MEASUREMENTS REQUIRED See attached sheet (page 144)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
NONE	0	0

MEASUREMENTS REQUIRED

Parameter	Instrumentation	No. of Sensors
Program time	Airborne computer-programmer	1
Programmed parameters	Airborne computer-programmer	5
Measured integral of acceleration	Airborne computer-programmer	1
Integral of acceleration error	Airborne computer-programmer	1
Vehicle attitude (three-axis)	Airborne computer-programmer	3
Command pitch attitude	Airborne computer-programmer	1
Command bank attitude	Airborne computer-programmer	1
Error signals to FCS	Airborne computer-programmer	3
Backup system diagnostics	Strapdown sensors, computer-programmer, power supply	25+
All primary system measurements tabulated in Task GN-1	See Task GN-1	135+

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Autonomous Orbital Navigation	GN-3

1. Technology Status Assessment

For some operational missions, ground radar tracking in orbit cannot be relied upon to provide accurate initial position and velocity data. Unless autonomous orbital navigation is sufficiently accurate, uprange radar and communication nets during entry would be needed. These nets would be costly, since at least 4 would be required to provide coverage from both approach directions.

For rescue or satellite inspection missions in which re-entry will occur within a few orbits after launch or after satisfactory ground track in orbit, autonomous orbital navigation could simply consist of self-contained inertial computations or of preprogrammed orbital trajectories which assume that the commanded orbital maneuver has been perfectly executed. In such situations, three-axis position and velocity need not be computed using optical tracking data. However, the use of star trackers to determine precision attitude alone would remain a valuable research task, since improved attitude accuracy is necessary to avoid dependence on the one tracking radar at the landing site (table 8).

2. Justification for Test on the Research Vehicle

The performance of star, earth landmark and horizon trackers cannot be adequately evaluated by ground tests--primarily because of atmospheric effects on optical waves. The optimum airborne filtering techniques can only be determined during orbital flight.

Autonomous orbital navigation testing can perhaps be more economically conducted during longer duration MOL- or MORL-type missions. However, the proposed research task emphasis is on the initial condition accuracy of navigation data in a specific coordinate frame referenced to the input axes of the re-entry inertial navigation sensors. A major error source is the misalignment between optical sensor axes and inertial sensor axes, due to such causes as gimbal angle transducer errors, structural deformations, initial calibration, etc. For example, if optical tracker size and look angle constraints preclude mounting them on the inner platform gimbal along with the inertial navigation sensors, then a strapdown inertial system has the advantage of fewer gimbal transducers and coordinate conversions. Subsequent inertial navigation performance during re-entry may provide the best measurement norm of the orbital navigation precision, at least with regard to initial attitude alignment.

3. Crew Tasks During Experiment

Man can significantly aid in the autonomous navigation process by programming the optical trackers. By utilizing aided tracking control modes to orient the tracker gimbals and/or the vehicle axes and thereby to recognize and acquire optical targets, the airborne digital computer-programmer functions will be simplified. Man can also initiate and sequence ground controlled tests.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. GN-3
Autonomous Orbital Navigation	RANKING 27

OBJECTIVE

To determine accuracy of measuring three-axis position, velocity and attitude in orbit without dependence upon ground tracking--with special emphasis on precision attitude.

DESCRIPTION

This experiment will measure and record the above navigation data during orbital flight. The autonomous sensors will include star, earth landmark and/or horizon trackers. The computed navigation data will be compared to the baseline navigation data. The baseline system determines position and velocity by ground tracking, and attitude by airborne horizon tracking plus gyro-compassing for yaw. Manual programming of the sensors (energization, slewing, acquisition, mode selection, etc.) will be utilized. Sensors require various fields of view and optical windows.

Experimental equipment will include, in addition to the optical sensors, strapdown inertial sensors, a digital computer and a precision power supply. These are independent of the baseline equipment.

This task is to be done in conjunction with Research Task GN-4.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C or F	Max. 2, Min. 1
Type G	Max. 2, Min. 1

MEASUREMENTS REQUIRED See attached sheet (page 148)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS

Star, earth landmark and/or horizon trackers
Strapdown inertial sensor package
Digital computer, precision power supply

WEIGHT (LB) 150 (68 kg)

POWER (WATT) 300

MEASUREMENTS REQUIRED

Parameter	Instrumentation	No. of Sensors
Stellar reference angles	Optical tracker (star)	2
Earth reference angles	Horizon or earth landmark tracker	2
Three-axis position, velocity, attitude	Digital computer experimental package	9
Diagnostics	Experimental package	35+
Three-axis attitude	Airborne baseline primary and back-up inertial systems	6
Local vertical attitude	Baseline dual horizon scanners	4
Time reference	Airborne timer	1
Ground computed position, velocity, time	Ground complex	7

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Inertial Navigation Error Propagation	GN-4

1. Technology Status Assessment

As discussed under Task GN-1 justification, inertial navigation error propagation has been measured for gimbaled platform systems during Gemini entry flights and during ascent boost on many vehicles. Strapdown inertial navigators have not yet been flight tested, and analysis indicates that their drift due to vibration and acceleration will be appreciably greater than with platform types.

2. Justification for Test on the Research Vehicle

The inertial navigation error propagation equations during entry, as approximated in Ref. GN-1, are appreciably complicated (relative to a supersonic cruise vehicle) by the large variation in the term $(g - V^2/R)$. This term is approximately zero at initial entry, and increases to about 1 g below hypersonic speed. By inputting the anticipated trajectory conditions throughout entry, ground digital computer simulation programs can provide an approximate but good evaluation of navigation error sensitivities to individually simulated perturbations. However, the actual perturbation environment is difficult to estimate, and the in-flight performance is sensitive to the re-entry acceleration and vibration environment. This sensitivity is especially important for a strapdown inertial system, which approach offers advantages over the baseline platform system in terms of size, weight, power and orbital alignment simplicity.

It can be argued that inertial error propagation could be more economically evaluated in an unmanned flight such as PRIME. However, the PRIME navigation and guidance system does not compute position nor three-axis velocity; it is equivalent to the proposed baseline backup guidance system. Installation and flight testing of a full strapdown inertial navigator in the PRIME vehicle, or in an enlarged but unmanned version, would perhaps suffice. However, such verification would not be nearly as convincing as simultaneous performance evaluation of a strapdown and a platform system in the same environment.

3. Crew Tasks During Experiment

The inertial navigation computations will be strictly automatic. Man's function (after initialization) will be limited to monitoring the outputs of all (3) systems and acting as a malfunction detector for manual switchover.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. GN-4
Inertial Navigation Error Propagation	RANKING 6

OBJECTIVE

To measure propagation of three-axis position, velocity and attitude errors throughout the entry and boost phase environments.

DESCRIPTION

This experiment will measure and record the above navigation data. The experiment package will be a strapdown inertial guidance system, and its digital computer signals will be recorded for comparison with those of the primary (gimbaled) IGS and the backup guidance system. This experiment will be done automatically. Particular emphasis will be placed on measuring environmental conditions (error contributors), e.g., thrust, drag and vibratory accelerations, angular rates, etc. Initial conditions at orbit departure should be precisely measured.

The inertial navigation equipment could be common with that provided for Task GN-3.

This task must be preceded by at least one flight in which Research Task GN-2 is programmed.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Types C, F	Max. 2, Min. 1
Type G	Max. 2, Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Three-axis position, velocity, attitude	Experimental package digital computer	9
Diagnostics	Experimental package	35+
Baseline primary and backup navigation measurements	See Tasks GN-1 and GN-2	100+

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Strapdown initial sensor package Digital computer Precision power supply	WEIGHT (LB): 100 (45.4 kg) POWER (WATT): 200

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Hypersonic Re-entry Guidance Techniques	GN-5

1. Technology Status Assessment

Hypersonic guidance technology status and potential operational problems are discussed under Task GN-1 Justification. The major objectives of flight testing hypersonic guidance concepts other than the baseline system (Task GN-1) would be the following:

(1) Realization of maximum practical crossrange maneuverability for the specific (HL-10) vehicle entering from a low earth orbital mission.

(2) Improved display capability.

(3) Improved performance capability for malfunction-type entries. These represent much worse than 3σ initial condition errors, such as following a launch abort or partial failure of the deorbit propulsion system. Barring such malfunctions, the along-range maneuverability requirements are minimized by proper deorbit timing.

(4) Minimization of control actuation requirements.

(5) Verification of guidance concepts for higher velocity entries, with more stringent vehicle constraints.

(6) Evaluation of guidance concepts for higher L/D vehicles.

Crossrange maneuverability (Item 1) is the main purpose of hypersonic L/D, and its practical utilization depends on how well the maximum L/D can be predicted or measured as a function of Mach and α. Unless variations in maximum L/D with Mach and α can be measured during flight more accurately than they can be predicted before flight, predictive guidance schemes are difficult to justify. For example, a major design objective of the Bell entry guidance scheme (ref. 3) is to enable continuous in-flight measurement of instantaneous L/D in order to improve crossrange capability. However, α must be precisely known to accurately compute L/D. Flight testing of such a sophisticated predictive scheme for operational performance optimization may prove warranted on later flight tests, assuming the vehicle L/D ratio proves measurable by precision α instrumentation via inertial navigation.

With regard to hypersonic energy management displays, the remaining maneuver capability (along range and crossrange) is a predictable function of instantaneous velocity. For alternate site selecting using the baseline implicit scheme, the measured velocity and velocity error (from nominal) are displayed; knowing the distance between the primary and the alternate landing sites, the pilot can insert the alternate site coordinates provided his displayed velocity conditions are satisfactory. This requires some simulation training. A footprint-type display would provide better operational flexibility for alternate site maneuverability. This display can be precisely mechanized (ref. 3), or it can be approximately generated using a simple implicit technique (ref. 4).

Items 3 and 4 will have been extensively simulated and evaluated as part of the baseline system design. Piloting capabilities and limitations, respectively, are important here. For example, the one plausible situation requiring extreme shortening of downrange distance, namely the failure of a finite number of deorbit engines, could best be compensated by manual guidance during the early entry phase. The re-entry error magnitude will be known as a function of the number of engine failures, so that based on simulator training the pilot will follow a predetermined sequence of roll maneuvers. These maneuvers will return the vehicle to the nominal energy management trajectory as quickly as possible consistant with g, heating rate and dynamic pressure constraints, after which the implicit guidance commands can be automatically generated. Flight testing of more sophisticated guidance techniques, therefore, appears justifiable in terms of flexibility and optimization with regard to Items 3 and 4 (e.g., using the closed form equations in ref. 5).

Guidance for supercircular entry velocities (Item 5 secondary objectives) requires more sophisticated guidance computations and control modulation techniques, at least through the initial skip. A modified implicit guidance law should be adequate, such as mechanized for Apollo, and closed form solutions have proven very satisfactory (ref. 5).

Techniques applicable to higher L/D vehicles could also be evaluated (Item 6), but complete verification by an HL-10 flight test is not possible because of differences in vehicle trajectory and re-entry flight duration.

2. Justification for Test on the Research Vehicle

Although hypersonic guidance concepts can and must be adequately evaluated by extensive ground simulations, operational verification and optimization require flight demonstration.

3. Crew Tasks During Experiment

When guidance displays are being generated by research equipment (e.g., aimed at maximizing L/D and therefore crossrange), it would be better to have the copilot execute the research task commands as displayed, while the pilot monitors the flight performance by comparison with the outputs of the baseline primary and backup guidance systems. The pilot would override the copilot if warranted.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. GN-5
Hypersonic Re-entry Guidance Techniques	RANKING 8

OBJECTIVE

Relative performance evaluation of guidance techniques (e.g., implicit versus explicit schemes) both for manual and automatic control modes.

DESCRIPTION

See attached sheet (page 155)

FLIGHT CONDITIONS	NO. OF FLIGHTS
Types C, D or F	Max. 2, Min. 1
Type G	Max. 2, Min. 1

MEASUREMENTS REQUIRED See attached sheet (page 156)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Strapdown inertial sensors, digital computer, precision power supply, guidance displays	WEIGHT (LB): 200 (90.7 kg) POWER (WATT): 300

DESCRIPTION

The experimental package will consist of strapdown inertial sensors, digital computer, precision power supply and displays. The inertial navigator could be common with that provided for Tasks GN-3 and GN-4.

Predictive and/or closed form guidance schemes will be flown, and data will be recorded and compared to data generated by the baseline implicit scheme. Guidance commands generated by the experiment package will be displayed (e.g., footprint display) and executed by the pilot. The baseline implicit commands (e.g., α and ϕ) will also be displayed and recorded with pilot option of switching to the implicit scheme in case of malfunction. Manual guidance performance will be compared to automatic guidance modes and various pitch-roll control concepts evaluated.

Finally, since piloting capabilities are quite subjective, one or more pseudo-pilots could fly the same or an alternate guidance scheme to evaluate actual performance in the same re-entry environment. This would require a separate computer, for each pseudo-pilot, to generate the guidance displays in accordance with vehicle trajectory and attitude conditions that would result from the pseudo-pilot command inputs of α and ϕ. The pseudo-pilot, however, must not be confused by having an outside view of his orientation nor by erroneous acceleration "feel." This acceleration feel problem can be minimized by slow execution of α and ϕ commands, since slow guidance response will cause negligible performance degradation. Although valid flight test experiments by pseudo-pilots throughout the hypersonic flight phase will be difficult to instrument and execute, their incorporation warrants further study--i.e., pilot in the loop simulations. Added experimental weight and power requirements (not included herein) would be involved.

This task must be conducted in conjunction with Task GN-4 and separately from Tasks GN-1 and GN-2.

MEASUREMENTS REQUIRED

Parameter	Instrumentation	No. of Sensors
Three-axis position, velocity, attitude	Experimental package computer	9
Command α	Experimental package computer	1
Measured α	Experimental package computer	1
Command ϕ	Experimental package computer	1
Error signals to FCS	Experimental package computer	3
Diagnostics	Experimental package computer	60+
Energy management display data	Experimental package displays (photos, perhaps)	3
Baseline primary and backup system measurements	See Tasks GN-1 and GN-2	60

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Terminal Navigation and Guidance Techniques	GN-6

1. Technology Status Assessment

As discussed under Task GN-1, terminal guidance flights from Mach 2 to touchdown (X-15 and planned medium L/D drop test programs) rely upon pilot visual observations for navigation. An all weather capability is needed for operational missions. Computer simulation studies to date of automatic terminal guidance are limited (ref. table 9). A major question is the need for landing propulsion assist to compensate for in-flight perturbations, assuming an operational airstrip size.

2. Justification for Test on the Research Vehicle

Much of the design optimization and verification can and should be accomplished by ground computer simulation and drop test flights. However, the drop test vehicle sensors and instrumentation, as currently planned, are markedly inadequate. Moreover, the Mach 2.0 initial condition errors due to hypersonic perturbations, along with the inertial navigation corrections (based on ground commands) prior to Mach 2.0, are significant factors affecting mission operation. Demonstration of operational capability, and even a valid comparison of ground based versus inertial updated guidance, requires complete re-entry flights.

3. Crew Tasks During Experiment

Navigation position and velocity update commands will be transmitted at intervals. These will be compared to onboard data by the pilot or navigator, and inserted (by keypunch) into the strapdown system computer. The guidance commands, generated by the airborne computer in accordance with the updated navigation data, will be executed by the copilot, with pilot override provision based on displayed air data and visual observations of the landing site. When flying automatic landings using ground commands, the pilot will monitor and take over as necessary.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. GN-6
Terminal Navigation and Guidance Techniques	RANKING 18

OBJECTIVE

To evaluate more flexible navigation and guidance techniques applicable to operational mission approach patterns and landings.

DESCRIPTION

This experiment will evaluate operational capabilities over and above those provided by the baseline system, with emphasis on:

(1) Landing approach patterns (e.g., spirals and 180-deg turns) with both minimum and maximum dependence on ground aid.

(2) All weather landing performance.

Experimental equipment will include the strapdown inertial system used for Tasks GN-3, GN-4 and GN-5 with provisions for correcting its three-axis position and velocity data based on precision ground radar data, plus airborne electronics to operate with airport landing aids (such as TACAN-type approach aids and short range radar systems for fully automatic landing). This task is required to be programmed with Task GN-4 and to be preceded by one flight on which Task GN-2 is loaded.

Navigation sensor and guidance command signals will be recorded and evaluated for various schemes--e.g., all airborne, all ground based, ground updating of airborne system. The pilot will monitor or execute the guidance output commands (pitch, roll and possibly drag brake or thrust) and have override provisions. Of particular interest are the comparable accuracies of various sensors (including ground radar) to measure h, $\dot{h}$, range, crossrange, heading, airspeed, α, β, etc.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A, B and S is suitable.	Min. 2 Max. 4

MEASUREMENTS REQUIRED See attached sheet (page 160)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
Strapdown inertial sensors, digital computer, precision power supply, transponders, radar altimeter	WEIGHT (LB) 175 (79.4 kg)
	POWER (WATT) 400

MEASUREMENTS REQUIRED

Parameter	Instrumentation	No. of Sensors
Three-axis position, velocity, attitude	Strapdown digital computer	9
Command and measured α	Strapdown digital computer	2
Command ϕ	Strapdown digital computer	1
Error signals to FCS	Strapdown digital computer	3
Diagnostics	Strapdown digital computer	60+
Energy management displays	Experimental displays	3
Updata signals	Airborne command receiver	8
Time reference	Timer	1
Air data signals	Air data system electronics	9
Tracking data	Airborne experimental sensors	3
Altitude signals	Airborne radar altimeter	1
Baseline primary and backup system measurements	See Tasks GN-1 and GN-2	60
Navigation and guidance measurements	Ground-based tracking (radar and optical) and computing facilities	25

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Air Data Measurements	GN-7

1. Technology Status Assessment

The X-15 and the drop test vehicles use air data measurements for control system gain programming and for display generation (e.g., angle of attack). Air data signals could also provide redundant navigation and guidance measurements (e.g., α, h, air-speed, etc.). A major problem for operational re-entries is heat protection for the sensor probes.

2. Justification for Test on the Research Vehicle

Air data system electronic operation and pilot utilization could well be evaluated during the drop test program, but their locations and heat protection devices are peculiar to the hypersonic vehicle design, to possible ablation effects and somewhat to vehicle size. Also, navigation capabilities above Mach 2 would be evaluated.

3. Crew Tasks During Experiment

The pilot will monitor the displayed data, and possibly utilize this data during the approach and landing phases of flight.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. GN-7
Air Data Measurements	RANKING 31

OBJECTIVE

To evaluate performance (accuracy, range, etc.) of air data systems during entry, plus sensor probe heat protection techniques.

DESCRIPTION

Equipment for air data measurement will be flown "piggyback," and pertinent signals recorded and compared. These signals will include Mach number, airspeed, h, $\dot{h}$, α, β, q. Since sensor location is critical, two or more identical sensors per flight may be evaluated. Measurement emphasis will be placed on the re-entry phase from 130 000-ft (39.6 km) altitude to landing (after peak heating) and on performance degradation with altitude. In order to properly set up this experiment, at least one flight in which Task GN-1 is conducted is required to precede Task GN-7.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A, B and S is suitable.	Min. 2 Max. 6

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Air data signals	Air data equipment	20
Primary and updated strap-down inertial (Task GN-6) computer signals	Airborne digital computers	60
Ground navigation data	Ground tracking complex	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB) / POWER (WATT)
Air Data Sensor Probes and Associated Electronics	WEIGHT (LB): 50 (22.7 kg) POWER (WATT): 75

PRECEDING PAGE BLANK NOT FILMED.

RESEARCH TASK SUMMARY

N. FLIGHT CONTROLS	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
FC-1 Flight control system evaluation	X			X	X	X	X	X	X					X		X			X	
FC-2 Adaptive flight control system		X		X	X	X	X	X	X					X		X			X	
FC-3 Digital flight control mechanization		X		X	X	X	X	X	X					X		X			X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Flight Control System Evaluation	FC-1

1. Technology Status Assessment

Because of test perturbation requirements (e.g., for Tasks FM-2, 3 and 4), the FCS design criteria for the research vehicle are perhaps more severe than for potential near-earth operational missions. These baseline design criteria are at least compatible with such operational requirements, including launch abort and other malfunction situations. However, for research flights, faster response and improved accuracy appear desirable. Response to these commands will also introduce actuation power requirements higher than necessary for operational missions.

Research performance requirements as well as current technology status indicate the use of conventional hydraulic actuation of the elevon and rudder control surfaces. However, size, weight, power and functional considerations strongly suggest a pilot fly-by-wire technique for electrical generation of command signals from his hand controller--e.g., Dyna-Soar design. This is a significant change from the FCS design for the HL-10, M2F2 and SV-5 drop test vehicles, in which the pilot has mechanical restraint of the control surface actuators. The FCS redundancy provisions must therefore be such that any potential malfunction be detected and switched out, and a redundant channel substituted, if necessary, before surface motions cause vehicle loss. Minimum redundancy requirements, in addition to dual reaction jets and hydraulic surface control actuators, include dual electrical transducers on the pilot's hand controller and dual stability augmentation (SAS) channels for each axis. The need for triple channels with a majority voting scheme for automatic switching depends on the pilot's ability to control the vehicle after a single channel SAS failure. Other potential problems include trim surface actuation versus Mach for improved performance, angle of attack (α) corridor constraints with Mach, and SAS gain variations with α, dynamic pressure (q) and Mach number.

Preliminary handling qualities data for the HL-10 drop test vehicle indicate that dual SAS channels may be adequate for operational missions. Dynamic stability problems appear to be greatest for the supersonic and transonic flight conditions, and the current design of the HL-10 drop test vehicle provides only dual lateral SAS channels; the second operates only as a monitor. The proposed baseline approach, however, incorporates redundant channels to enable completion of pilot research tasks despite a single channel failure.

In summary, the FCS baseline design is very preliminary in nature and will require additional wind tunnel data plus extensive simulation. Moreover, this subsystem design is critical because of potential catastrophic effects in case of a malfunction. The pilot's ability to monitor, correct and control results in an extremely important pilot-FCS interface. This interface optimization is dependent on vehicle characteristics and flight environment, and its definition requires pilot-in-the-loop simulations.

2. Justification for Test on the Research Vehicle

Before flight verification of any FCS design, comprehensive simulation programs will be conducted to evolve, refine and justify the baseline configuration. Nevertheless, extensive flight evaluation will be necessary. Such evaluations must include operational applicability as well as baseline design verification.

Some experimental results of the HL-10 drop test flights will be pertinent, such as the performance of the hydraulic surface control actuators. However, these results will be applicable only to low speed flight conditions. Moreover, the fly-by-wire pilot controller is not designed into the drop test FCS.

3. Crew Tasks During Experiment

Pilot contributions are extremely important, and his work load and responsibilities will be heavy. In addition to exercising manual control modes, he (or the copilot or navigator) must exercise his unique capabilities as a monitor and corrector for timewise critical FCS malfunctions.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FC-1
Flight Control System Evaluation	RANKING 13

OBJECTIVE

Determine applicability of baseline FCS equipment to potential operational missions.

DESCRIPTION

The flight control system actuates the reaction jets and/or the hydraulic surface controls in accordance with input commands from the pilot's hand controller or with automatic guidance inputs.

The performance of the manual and automatic modes of operation will be recorded and correlated with ground simulation results at comparable flight conditions. Critical evaluation criteria will be the measured vehicle response when various FCS failure modes are simulated, such as failure of one axis of stability augmentation; the ability of the pilot to control the vehicle will significantly affect the redundancy philosophy. Necessary operational improvements and/or feasible simplifications will be determined.

This task will stress the determination of operational equipment requirements, capabilities and limitations, as contrasted to the aerodynamic and handling quality research measurements for Tasks FM-2 through FM-6.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type C	1
Any condition except A and B is suitable.	Max. 7, Min. 3

MEASUREMENTS REQUIRED (page 169)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
NONE	0	0

MEASUREMENTS REQUIRED: FC-1

Parameter	Instrumentation	No. of Sensors
ON time of reaction control thrusters	Solenoid valve signals	16
Elevon (2) and rudder actuator positions	Signal transducers	3
Hydraulic control actuator loads	Hydraulic pressure transducers	12
Trim surface settings	Signal transducers	6
Vehicle attitude rates	FCS rate gyros	3
Vehicle accelerations	Accelerometers	3
Automatic guidance commands	Airborne guidance computer	3
Vehicle attitudes	Airborne guidance computer	3
Pilot stick commands	Hand controller	10
FCS diagnostics	Electronic FCS signals	20
Air data	Air data signals	10
Structural response	Accelerometers	24

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Adaptive Flight Control System	FC-2

1. Technology Status Assessment

The desired gain programming is conventionally done in accordance with sensed air data signals, and presumes at least ball-park knowledge of vehicle aerodynamic derivatives. Adaptive FCS designs, as exemplified by that being flight tested in the X-15-3, minimize the above dependencies while providing improved handling quality and response rate capabilities. The need for this improved performance with the HL-10 vehicle does not appear essential for most operational missions. However, air data dependence after hypersonic heating poses some risk; a backup gain programming technique might utilize inertial navigation data, updated from ground tracking, below hypersonic speeds. Other potential advantages of an adaptive FCS, particularly for research flight testing, may evolve from more recent (than that in the X-15-3) and simplified adaptive techniques such as probability state variable feedback devices. These use variable identification schemes which help determine vehicle characteristics, but require much additional study.

2. Justification for Test on the Research Vehicle

Before flight verification of any FCS design, comprehensive simulation programs will be conducted to evolve, refine and justify the baseline configuration. Nevertheless, extensive flight evaluation will be necessary. Such evaluations must include operational applicability as well as baseline design verification.

3. Crew Tasks During Experiment

Pilot contributions are extremely important, and his work load and responsibilities will be heavy. In addition to exercising manual control modes, he (or the copilot or navigator) must exercise his unique capabilities as a monitor and corrector for time-wise critical FCS malfunctions.

RESEARCH TASK DEFINITION

TASK TITLE

Adaptive Flight Control System

TASK NO. FC-2

RANKING 29

OBJECTIVE

Evaluate performance of an advanced adaptive FCS and compare to that of conventional FCS (distinction is method of gain changing).

DESCRIPTION

An adaptive FCS mechanization will control the vehicle, and flight performance will be recorded and compared to results of previous flights with the conventional FCS. Evaluation criteria will include the need and ability to achieve maximum response rate compatible with system stability, transition between reaction and aerodynamic controls, control mode switching transients, redundant channel voting and switching performance, pilot ratings, required degree of knowledge of aerodynamic data, performance and reliability of air data sensors for conventional FCS gain programming, and any improved capability with the adaptive FCS to measure aerodynamic coefficients during flight, etc.

This experiment should not be programmed on the same flight as Task FC-1 and must be preceded by four flights on which Task FC-1 is programmed.

FLIGHT CONDITIONS

Any entry condition except A and B is suitable.

NO. OF FLIGHTS

Max. 3, Min. 1

MEASUREMENTS REQUIRED See attached sheet (page 172)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS

None: The adaptive FCS replaces the conventional FCS.

WEIGHT (LB)

0

POWER (WATT)

0

MEASUREMENTS REQUIRED: FC-2

Parameter	Instrumentation	No. of Sensors
ON time of reaction control thrusters	Solenoid valve signals	16
Elevon (2) and rudder actuator positions	Signal transducers	3
Hydraulic control actuator loads	Hydraulic pressure transducers	12
Trim surface settings	Signal transducers	6
Vehicle attitude rates	FCS rate gyros	3
Vehicle accelerations	Accelerometers	3
Automatic guidance commands	Airborne guidance computer	3
Vehicle attitudes	Airborne guidance computer	3
Pilot stick commands	Hand controller	10
FCS diagnostics	Electronic FCS signals	20
Air data	Air data signals	10
Structural response	Accelerometers	24

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Digital Flight Control Mechanization Using Centralized Digital Computer	FC-3

1. Technology Status Assessment

In view of the rapid advancement of digital computer technology status, it appears that optimum performance, reliability and flexibility will eventually result by accomplishing the FCS functions in a centralized digital computer. Titan III launch vehicle planning includes flight testing of a digital FCS.

2. Justification for Test on the Research Vehicle

Before flight verification of any FCS design, comprehensive simulation programs will be conducted to evolve, refine and justify the baseline configuration. Nevertheless, extensive flight evaluation will be necessary. Such evaluations must include operational applicability as well as baseline design verification.

3. Crew Tasks During Experiment

Pilot contributions are extremely important, and his work load and responsibilities will be heavy. In addition to exercising manual control modes, he (or the copilot or navigator) must exercise his unique capabilities as a monitor and corrector for time-wise critical FCS malfunctions.

RESEARCH TASK DEFINITION

TASK TITLE	TASK NO. FC-3
Digital Flight Control Mechanization Using Centralized Digital Computer	RANKING 30

OBJECTIVE

To evaluate performance of digital FCS and its interfaces.

DESCRIPTION

The functions of the electronic FCS, which are mechanized using analog-type circuits for the baseline system, would be mechanized as part of a centralized digital computer which would also accomplish the computational functions of navigation, guidance, in-flight checkout, malfunction detection and correction, air data processing, etc. Of particular importance are the man-machine interface and the form of the output signal to the control actuators. The initial flight would be flown piggy back, comparing the digital system to the controlling analog FCS. Subsequent flights would have the digital FCS circuitry controlling, but with provision for switching control back to the conventional FCS.

This task should not be programmed on the same flight as Task FC-2 and must be preceded by at least three flights on which Task FC-1 is programmed.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A and B is suitable.	Max. 3, Min. 1

MEASUREMENTS REQUIRED (page 176)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
Digital Computer	70(31.8 kg)	150

MEASUREMENTS REQUIRED: FC-3

Parameter	Instrumentation	No. of Sensors
ON time of reaction control thrusters	Solenoid valve signals	16
Elevon (2) and rudder actuator positions	Signal transducers	3
Hydraulic control actuator loads	Hydraulic pressure transducers	12
Trim surface settings	Signal transducers	6
Vehicle attitude rates	FCS rate gyros	3
Vehicle accelerations	Accelerometers	3
Automatic guidance commands	Airborne guidance computer	3
Vehicle attitudes	Airborne guidance computer	3
Pilot stick commands	Hand controller	10
FCS diagnostics	Electronic FCS signals	20
Air data	Air data signals	10
Structural response	Accelerometers	24
Digital FCS signals	Experimental digital computer	35

RESEARCH TASK SUMMARY

O. COMMUNICATIONS	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
AV-1 Antenna window material test		X		X	X	X	X	X	X	X	X			X				X	X	
AV-2 Satellite communications equipment		X		X	X	X	X	X	X	X	X			X				X	X	

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Antenna Window Material Test	AV-1

1. Technology Status Assessment

The development of antenna window material, i.e., material which is transparent to rf energy and which will withstand the re-entry environment (including ablation effects), must be verified by tests in an actual re-entry environment.

2. Justification for Test on the Research Vehicle

The hypersonic research vehicle is required to provide the required re-entry environment. An unmanned hypersonic flight would suffice.

3. Crew Tasks During Experiment

None.

RESEARCH TASK DEFINITION

TASK TITLE	
Antenna Window Material Test	TASK NO. AV-1
	RANKING 49

OBJECTIVE

Verify the results of the ground tests on the antenna window material in the actual space and re-entry environment.

DESCRIPTION

Measure the heat transfer characteristics of the window material. At the same time, the antenna impedance will be measured to verify the ground test results of antenna impedance measurements with simulated plasma.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Type B Any entry condition except A is suitable	1 Max. 2 Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Antenna impedance	Bi-directional coupler phase angle detector	14
Temperature	Thermocouples	4

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
NONE	0	0

RESEARCH TASK JUSTIFICATION

TASK TITLE	TASK NO(S).
Satellite Communications Experiment	AV-2

1. Technology Status Assessment

During the high heating portion of the re-entry, communications with the ground are not currently possible due to attenuation of the rf energy by the plasma. Although communication is not actually required during that portion of the flight, it is obviously desirable to maintain at least voice communication during this period of maximum stress on the vehicle. For potential operational missions, this would enable alternate landing site selection when maneuverability is still high. The proposed experiment will contribute to the development of a communication capability during re-entry by transmitting from the re-entry vehicle to a communications satellite which relays the signal to a ground station.

A satellite relay link poses some equipment and operational problems. Due to the requirement for flush mounted antennas on the re-entry vehicle and the desirability of broad beam antennas to avoid pointing problems, the re-entry vehicle antenna gain will be low, on the order of +3 db. With low antenna gain, a transmitter power output of approximately 100 watts will be required to provide voice communications using a relay satellite of the ATS-B (Applications Technology Satellite-B) class. Transmitters with 100-watt outputs are available, but they are heavy ($\approx$ 40 lb)(18.1 kg) and they consume large amounts of power ($\approx$400 w).

The operational problems stem from the requirement for a mid-Pacific communication satellite with multiple access capability and an effective radiated power of 200 watts for the comsat to re-entry vehicle link. The ATS-B has such a capability and is due to be orbited later this year for experiments in providing voice channels for transatlantic aircraft. If successful, worldwide deployment is anticipated. It is, therefore, not unreasonable to assume that a suitable relay satellite will be available during the operational period of the HL-10 research vehicle.

2. Justification of the Test on the Research Vehicle

The hypersonic research vehicle is required to provide the required re-entry environment.

3. Crew Tasks During Experiment

Provides the input signals for the re-entry vehicle to ground link (voice) and evaluates quality of ground-to-re-entry vehicle link.

RESEARCH TASK DEFINITION

TASK TITLE	
Satellite Communications Experiment	TASK NO. AV-2
	RANKING 44

OBJECTIVE

To provide continuous communications throughout the re-entry phase.

DESCRIPTION

This experiment is based on using a communications satellite in a synchronous orbit as a relay station for a communications link between the re-entry vehicle and the ground. An attractive feature is that the antenna location on top of the re-entry vehicle would have only a tenuous plasma covering it due to the angle of attack of the re-entry vehicle. Thus, the propagation losses would be small and the blackout region would be bypassed. The relay link would provide continuous communications throughout the re-entry period, supplementing the ground network. The link could also be used during the orbital portion of the mission to provide communications while beyond line-of-sight of the ground stations.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition except A is suitable.	Min. 1

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
None required--performance evaluated by crew		

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
100-watt VHF Transceiver VHF antenna on upper surface	WEIGHT (LB) 40(18.1 kg)
	POWER (WATT) 400

PRECEDING PAGE BLANK NOT FILMED.

V. REQUIREMENTS SUMMARY

As discussed in the introduction to this report, the cost and effectiveness analysis performed in this study required the identification of research task requirements such as equipment weight, instrumentation, crew time, flight constraints and entry conditions. These requirements are spelled out in some detail on the research task definition forms presented in Section II and are summarized herein for ready reference.

A. ENTRY CONDITIONS

On the research task definition form there is a section entitled "Flight Conditions." The data from this section is summarized for each research task in table 10 and is shown as a maximum and minimum requirement. The entry conditions listed under "maximum" and "minimum" were selected by examining the objective and description of each research task according to the data desired and the entry conditions best suited to yield that data. Maximum is defined as the combination of conditions beyond which no increase in value can be obtained. Minimum means the combination of conditions below which no appreciable value can be expected. The data are used in determining an information value ratio for the cost and effectiveness analysis discussed in Part VI.

B. CREW REQUIREMENTS

The amount of crew time available for research is a function of the number of crew on board,and this varies with the time over the mission profile. To assure identification of all significant phases of the mission it was divided into 12 flight phase segments. Detail crew participation requirements for each research task during each of these 12 time intervals are summarized in table 11. Crew participation is expressed as a utilization ratio (i. e. , the percentage of one crew member's capacity used to perform the research task in a given time interval). Utilization ratios were obtained by analysis of the various crew activities required to carry out the tasks as described in Section IV of this Part. These crew activities included: instrument monitoring, experiment termination or switchover, operation of experiment equipment, entry vehicle controlling, pre-entry checkout of experiment equipment in orbit and status reporting. Results of the crew task analysis show that 27 out of the 52 research tasks require crew participation. For most research tasks, the peak crew activity occurs near entry pullout. Basic crew functions will be required to perform the flight mission independent of the research tasks. Crew utilization for these basic tasks are shown for reference at the bottom of table 11. Further discussion of crew task analysis is found in Part V.

TABLE 10

SUMMARY OF ENTRY CONDITIONS VERSUS INFORMATIONAL VALUE

Research task No.	Entry conditions for value	
	Maximum	Minimum
SM-1	BC	B
FM-8	B + 6 (C, F)	B + 2 (C, F)
FM-3	C + 9 [A, B]	C + 3 [A, B]
FM-2	6 + (C, D, F)	2 (C, D, F)
FM-7	B + 6 (C, F)	B + 2 (C, F)
FM-4	4 [A, B]	2 [A, B]
GN-4	2 (C, F) 2G	1 (C, F) G
GN-5	2 (C, F) 2G	1 (C, D, F) G
FM-13	6 (C, D, F)	2 (C, D, F)
GN-1	2C4F4G	CFG
EV-2	10R	R
FC-1	C + 7 [A, B]	C + 3 [A, B]
FM-5	3 [A]	2 [A]
SM-6	B2C	BC
SM-2	2C	F
SM-8	10R	R
FM-17	3 (C, F) 2I	1 (C, F) I
GN-6	4 [A, B, S]	2 [A, B, S]
FM-14	6 (C, D, F)	2 (C, D, F)
GN-2	2C	C
SM-17	BC + 1 [A]	B
SM-7	B	--
SM-5	3 [A]	1 [A]
SM-9	10 [A, B]	1 [A, B]
SM-3	10 [A]	1 [A]
GN-3	2 (C, F) 2G	1 (C, F) G
FM-6	4 (C, F)	2 (C, F)
FC-2	3 [A, B]	1 [A, B]
FM-12	3 [A, H, S]	1 [A, H, S]

Research task No.	Entry conditions for value	
	Maximum	Minimum
FC-3	3 [A, B]	1 [A, B]
GN-7	6 [A, B, S]	2 [A, B, S]
SM-14	B + 1 [A]	--
FC-4	3 (C, F)	1 (C, F)
FM-15	3 [A, E, H, S]	2 [A, E, H, S]
PP-3	2 [A, B]	1 [A, B]
HF-2	10 [A, B]	1 [A, B]
SM-10	10 [A, B	2 [A, B]
SM-12	3H	G
PP-2	2 [A]	1 [A]
SM-13	6 [A]	2 [A]
PP-1	2 (ALL)	1 (ALL)
SM-11	3 (C, F)	1 (C, F)
SM-16	2C	1 (C, F)
AV-2	1 [A]	--
HF-1	3 [A, B, S]	1 [A, B, S]
FM-16	8 (C, D, F, I)	2 (C, D, F, I)
SM-15	D	[1 A, B, D, I, H]
FM-9	2J 2K	JK
AV-1	1 [A]	--
FM-18	1 [A]	--
SM-18	1 [A, B]	--
FM-19	2S	S
PP-6	B	--
SM-19	C + 3 [A, B]	C + 2 [A, B]
EV-1	B + 2 [A, B]	B + 1 [A, B]
FM-1	B	--
FM-20	ALL [A]	--
BL-4	BC	--
BL-10	A	--
BL-11	C + 1 [A, B]	C

[ ]: Except entry condition in bracket
N ( ): Any combination of entry conditions in parentheses for N flights.
R: Flight of refurbished entry vehicle

Example: B + 6 (C, F) symbolizes one flight of entry condition "B" plus six flight of either "C" or "F" conditions.

TABLE 11

WEIGHT AND CREW TASK REQUIREMENTS

Research task		* Weight	Ascent 0 - 8 min	1st orbit 8 - 98 min	2nd orbit 98 - 188 min	3rd orbit 188 - 229 min	Deorbit and exo-atmospheres 229 - 257 min	400 000 to 280 000 ft (122 to 85 km) 257 - 262 min	280 000 ft (85 km) to pullout 260 - 262 min	Pullout to 200 000 ft (61 km) 262 - 284 min	200 000 ft (61 km) to M = 6 284 - 287 min	M = 6 to M = 2 284 - 287 min	M = 2 to M = 0.8 287 - 289 min	Approach flare and landing 289 - 291 min
1	SM-1	0												
2	FM-8	20												
3	FM-3	0								Control .4	Control .3			
4	FM-2	0						1st flight 0 Other flights .5	1st flight 0 Other flights .5	1st flight 0 Other flights 5	1st flight 0 Other flights .5			
5	FM-7	0												
6	FM-5	0												
7	GN-4	100												
8	FM-4	0					Attitude control .1	Attitude control .1	Attitude control .1	(see FM-3) 0	(see FM-3) 0	(see FM-3) 0		
9	GN-5	100		Read/compare .1	Read/compare .1	Read/compare .1	Read/compare .2	Manual guidance 1.0	Manual guidance 1.0	Manual guidance .8	Manual guidance .5			
10	FM-13	0							(see FM-2) 0	(see FM-2) 0	(see FM-2) 0			
11	EV-2	0												
12	SM-6	50						Vary gap monitor temperature .1	Vary gap monitor temperature .1	Vary gap monitor temperature .1	Vary gap monitor temperature .1			
13	GN-1	0			Verifications .1		Verifications .1	Compare .1	Compare .1	Verifications .3				
14	FC-1	0								Control .2	Control .3			
15	SM-2	0												
16	FM-17	0								Operate boundary layer tripper .3				
17	SM-8	0												
18	GN-6	75									First flight .1 Other flights .8	First flight .1 Other flights .8	First flight .1 Other flights .8	First flight .1 Other flights .8
19	FM-14	0						(see FM-2) 0	(see FM-2) 0	(see FM-2) 0	(see FM-2) 0			
20	SM-7	0												
21	FM-6	250				Transfer ballast .2		Control attitude Adjust SAS gains .2	Control attitude .2	Control attitude Adjust SAS gains .4	Control attitude Adjust SAS gains .3	Control attitude Adjust SAS gains .2		
22	FM-12	0												
23	GN-2	0												
24	SM-5	10												
25	SM-17	0												
26	SM-3	10												
27	SM-9	10						Vary attitude read temperature .2	Vary attitude read temperature .2	Vary attitude read temperature .1				
28	FC-2	0			C/o adapt. FCS .1					Monitor FCS Switch if required .1	Monitor FCS Switch if required .1			
29	GN-3	50		Align/read .3	Align/read .3	Align/read .3	Align/read .1							
30	FC-3	70			C/o computer .1		C/o computer .1			Control modes Monitor FCF .1	Control modes Monitor FCS .1			

*Experiment equipment requirements

TABLE 11--Concluded

Research task		* Weight	Ascent 0 - 8 min	1st orbit 8 - 98 min	2nd orbit 98 - 188 min	3rd orbit 188 - 229 min	Deorbit and exo-atmospheres 229 - 257 min	400 000 to 280 000 ft (122 to 85 km) 257 - 262 min	280 000 ft (85 km) to pullout 260 - 262 min	Pullout to 200 000 ft (61 km) 262 - 284 min	200 000 ft (61 km) to M = 6 284 - 287 min	M = 6 to M = 2 284 - 287 min	M = 2 to M = 0.8 287 - 289 min	Approach flare and landing 289 - 291 min
31	FM-15	15												
32	PP-3	150								C/o engine .4				Open inlet start engine 1.0
33	PP-2	0						Operate jets Monitor response .1	Operate jets Monitor response .5	Operate jets Monitor response .3	Operate jets Monitor response .2			
34	GN-7	50												
35	SM-14	35												
36	HF-2	20												
37	FC-4	200				C/o actuator .1			Monitor system Switch if required .1	Monitor system Switch if required .1	Monitor system Switch if required .1	Monitor system Switch if required .1		
38	SM-10	0												
39	SM-12	0												
40	SM-13	0												
41	PP-1	0			Control entry vehicle attitude .2									
42	SM-16	0												
43	AV-2	40							Communicate monitor .2	Communicate monitor .2				
44	SM-11	125						Start pumps .1	Monitor flow rate .2	Monitor flow rate .2	Monitor flow rate .2	Monitor flow rate .2		
45	HF-1	500			Crew transfer EVA** 1.0		Exchange crew 0 New pilot .6	Exchange crew 0 New pilot .8	Exchange crew 0 New pilot .8	Exchange crew 0 New pilot .7	Exchange crew 0 New pilot .8	Exchange crew 0 New pilot .8	Exchange crew 0 New pilot 1.0	Exchange crew 0 New pilot 1.0
46	FM-16	40												
47	SM-15	80					Pressurize system .1	Monitor system .1	Adjust flow rate 1.0	Adjust flow rate .8	Adjust flow rate .2			
48	FM-9	25												
49	FM-18	200							Extend and jettison antenna .5	Extend and jettison antenna .5				
50	AV-1	0												
51	FM-19	0				α and φ manual program .5	Check entry condition .4	α and φ reprogram .2	α and φ reprogram .3					
52	SM-18	300		EVA** 1.0	EVA** 1.0									
Normal flight tasks	PP-6 SM-19 EV-1 FM-1 FM-20 BL-4 BL-10 BL-11		Monitor MDS communicate with MCC .5	Attitude control flight status .5	Orbit determination flight status .5	Orbit determination entry flight preparation .4	Adapter separation retro sequence attitude control .6	Communicate flight status attitude control .8	Flight path status attitude control .9	Flight path and attitude control .7	Flight path and attitude control communicate .8	Flight path and attitude control communicate .8	Flight path and attitude control communicate 1.0	Flight path attitude control communicate 1.0

*Experiment equipment requirements

**Entry vehicle attitude

C. RESEARCH TASK WEIGHTS

Weight requirements for research tasks consist of (1) instrumentation and prorated telemetry equipment needed to carry out measurements and (2) the research equipment weight other than instrumentation and telemetry. It became evident early in the study that a large portion of the total research measurements called for common instruments. It was then decided to include the instrumentation and signal conditioning weight as part of the basic entry vehicle, allowing for enough channels to handle the greatest experiment loading flight. This weight was derived from the most densely loaded flight of a series of 11 flights, wherein the experiment loading plan was obtained from a preliminary analysis. The number of channels required for this case totaled 2000.

The research equipment weight then was estimated by listing only the major components for the research task, the weights installed and the equivalent battery weight for electrical power. The equipment description and the equivalent weights are described in Section IV of this Part. Weight data are summarized for all the research tasks in table 11.

D. RESEARCH TASK CONSTRAINTS

Many of the research experiments are constrained in their assignment on flights relative to others. Three types of constraints are used in this study.

(1) Conjunctive--prescribes experiments which must be assigned on flight along with subject experiment.

(2) Exclusive--prescribes certain experiments which must not be assigned on the same flight as the subject experiment.

(3) Prerequisite--prescribes experiments and the number of treatments that are required to precede the subject experiment.

Research task flight loading constraints are summarized in table 12. The primary source of these constraints is the Research Task Descriptions of Section IV of this Part. Conjunctive constraints are applied where greater efficiency is gained by loading two tasks together on one flight or where a major piece of experimental equipment would be common to two tasks. Exclusion constraints simply prevent two tasks whose objectives and functions are opposed, and, as such, neither experiment could be effective. Prerequisite constraints were established principally to avoid conducting of experiments prematurely (i.e., before necessary prerequisite information could be acquired and reviewed).

TABLE 12

RESEARCH TASK 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	SM-11		(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 Any (2)		
38	SM-12	SM-9		
39	PP-2			(4) FC-1
40	SM-13			

TABLE 12--Concluded

Rank	Research task	Load with	Do not load with	Prerequisite
41	PP-1			
42	SM-11	SM-9		
43	SM-16			
44	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	FM-19			(4) FC-1
	PP-6			
Base	SM-19			
Line	EV-1			
	FM-1			
Tasks	FM-20			
	BL-4			
	BL-10			
	BL-11			

Parentheses indicate number of flights in which experiment is loaded.

VI. RESEARCH TASK INTRINSIC VALUE

A. GENERAL CONSIDERATIONS

During this study, numerical values were determined for each research task that are indicators not only of the inherent worth of each of these research tasks but its worth relative to all the other research tasks. It was necessary to establish the inherent worth (or intrinsic value) of the research tasks so that the flight loading effort could be completed.

The task referred to as flight loading of research tasks is an effort to find the optimum grouping of tasks, by flight, and the optimum sequence for conducting the tasks throughout the research flight program. Since in any optimization problem the task is either to maximize the value obtained from spending resources or, conversely, to minimize the spending of resources, to obtain some constant value, the importance of establishing a value for each research task can be seen.

An ideal way to establish the intrinsic value would have been to establish, in some manner, the benefits that would accrue to some future operational program by performing the research task within the context of the entry research program. Once having established these benefits, an attempt would be made to assess the cost savings possible and thus determine the value of the particular task in terms of dollars. No practical means was uncovered to do this. Therefore, the following techniques were investigated.

B. TECHNIQUES CONSIDERED

Since the defined research tasks had no directly measurable physical characteristics, no practical means was available for relating the research to any characteristic such as "dollars saved on future operational programs." The effort therefore was directed to measuring techniques not requiring a physically measurable attribute. A brief discussion of each of the techniques considered is presented below.

1. Rank Order Selected Scale

In this technique, the analysts (group of technical experts) rank the tasks from most important to the least, and then try to fit some selected scale of value to this ranked list. The scale could be linear, exponential, etc. This technique is arbitrary and not very time-stable (i.e., if the same group of experts repeated the job in a month, the results would probably be quite different).

2. PATTERN MSFC

PATTERN (Planning Assistance Through Technical Evaluation of Relevance Numbers) was devised by Honeywell Military Products Group and used in a Marshall Space Flight Center Project. The opinion of experts suitably challenged, a computer and an embracing structure comprise the system. Adaption of this very complex technique appeared to be beyond the scope of and unsuitable for the Manned Lifting Body Study.

3. Mutual Agreement

In this technique, only a few people are involved so as to allow assignment of value by some intuitive scheme which is mutually acceptable to all concerned. It was felt that the technique was much too arbitrary to be acceptable.

4. Law of Comparative Judgment

Originally developed as a psychophysical method for making measurements in psychological studies, this method has since been applied to many cases where it is necessary to establish a scale of values. It provides an excellent means of determining a scale of values for the research tasks that is time-stable. This law is formulated by a set of equations which relate the proportion of times that one research task is judged better than another to a position on a value scale.

C. SELECTED TECHNIQUE

The technique selected for establishing the intrinsic value of the research tasks is a method called the Law of Comparative Judgment. For a discussion of the derivation of the general law, as developed by Thurstone, the reader is directed to reference 1. However, a brief discussion of the derivation of this law and the special case of it used is given in the context of this application, which follows.

The Law of Comparative Judgment is a set of equations that relate the percentage of times any research task, k, is judged greater in selected attributes than any other research task, j. The selected attributes in the case of this study are listed in the following subsection. The equations also relate the standard deviations of frequency distributions associated with each of the research tasks. The frequency distributions referred to will be discussed in more detail later. The set of equations referred to are developed from a set of four postulates:

(1) Each research task, when presented to a subject (in this study any one of the eleven persons serving as judges, each well versed in lifting body technology), gives rise to a sensation or opinion which has some value on a linear scale.

(2) Each time the same research task is considered by a given judge his evaluation may not be the same; the value of the task when he reconsiders it may be greater or less than his earlier judgment. If this process is repeated a large number of times, frequency distribution of the judge's opinions will result. It is postulated that this frequency distribution will approximate a normal distribution. Thus, each research task has associated with it a normal distribution of opinions.

(3) The mean associated with the frequency distribution of a judge's opinion of each research task is taken as its scale value, while the standard deviation of the distribution is called the discriminal dispersion.

(4) If two research tasks, j and k, are presented to one observer (judge), each will elicit an opinion, d_j and d_k, respectively. If these two tasks are presented to the same observer many times the difference, $d_j - d_k$, will also form a normal distribution. The mean of this distribution is equal to the difference in scale values of the two research tasks since the difference between means of two distributions is equal to the mean of the distribution of differences. From the well known formula for the standard deviation of differences:

$$\sigma_{d_k - d_j} = (\sigma_j^2 + \sigma_k^2 - 2\, r_{jk}\, \sigma_j\, \sigma_k)^{1/2} \qquad (1)$$

With the above postulates, the derivation of the complete Law of Comparative Judgment can be simply shown. Since a distribution of differences is developed when two research tasks are presented together many times to the same judge (or once to a number of different judges) and since the mean of this difference distribution is equal to the difference in scale value of the two research tasks ($S_k - S_j$), the following is true. From the proportion of times research task k is judged of greater value than research task j, we can determine the difference ($S_k - S_j$) from a table of areas under the unit normal curve. This difference, called x_{jk}, is the mean of the normal difference distribution and is measured in $\sigma_{d_k - d_j}$ units. Thus,

$$S_k - S_j = x_{jk}\, \sigma_{d_k - d_j} \qquad (2)$$

and substituting equation (1) for $\sigma_{d_k - d_j}$ gives the complete Law of Comparative Judgment

$$S_k - S_j = x_{jk}\, (\sigma_j^2 + \sigma_k - 2 r_{jk}\, \sigma_j\, \sigma_k)^{1/2} \qquad (3)$$

where S_j, S_k = scale values of research tasks j and k.

σ_j, σ_k = standard deviations of the frequency distribution for research tasks j and k as stated earlier in postulate (2).

r_{jk} = correlation between the pairs of opinions d_j and d_k (postulate (4) describes d_j and d_k)

x_{jk} = normal deviate corresponding to the proportion of times research task k is judged of greater value than research task j.

As Torgerson shows (ref. 1), the Law of Comparative Judgement is not solvable in its complete form since, regardless of the number of research tasks, there are always more unknowns than there are observation equations. Thus, some simplifying assumptions are necessary to make this law useful.

For this application, two simplifying assumptions were made: equal correlations and equal standard deviations of the frequency distributions (i.e., $\sigma_j = \sigma_k = \sigma$ and $r_{jk} = r$). This assumption is considered reasonable in view of the general similarity of the research tasks. Other approaches would require a significantly larger group of judges with specific knowledge of the proposed research tasks and much more analysis, both of which were beyond the scope of this study. Thus, the complete form of the Law of Comparative Judgment, equation (3), reduces to

$$S_k - S_j = x_{jk} \; \sigma \left[2 \; (1 - r)\right]^{1/2} \tag{4}$$

However, since the term $\sigma \left[2 \; (1 - r)\right]^{1/2}$ is simply a multiplying constant, the final form used for this application was

$$S_k - S_j = C \; x_{jk} \tag{5}$$

and as shown in subsection E, the unit of measurement was chosen arbitrarily to make C equal to unity. This form of the law is referred to by Torgerson as "Class II Condition C."

D. EXPERIMENTAL PROCEDURE

As can be seen from equation (5), it is necessary to obtain data for each and every pair of research tasks in the form of "the proportion of times research task "k" was judged of more value than research task "j." The direct method for accomplishing this is called "the method of paired comparisons." In the method of paired comparisons, as applied to this study, each subject was required to compare each research task with each other research task and judge which one of the pair had the higher value. Since there were 52 research tasks, there were $\frac{52\ (52-1)}{2}$ = 1326 pairs or 1326 specific judgments required. Eleven subjects participated and were asked to judge each pair of tasks on the basis of five attributes with the task having more judged of higher value. The attributes considered were as follows:

(1) Contribution to technology increase

(2) Obtainment of design data

(3) Reduction of operational lifting body vehicle development time span

(4) Elimination of prototype phase in development

(5) Decreasing the total lifting body entry vehicle development cost.

Table 13 shows a typical example of the form that was developed for this effort. Research tasks were placed on this form in a random manner. Each subject was asked to complete the form indicating his preference for row over column by placing a zero in the appropriate block. For a preference of column over row, he was asked to indicate the preference by a 1 in the appropriate block. As will be discussed below, the data were then transferred to IBM cards for use in a special data reduction computer program prepared for this effort.

E. ANALYTICAL TECHNIQUES

Application of the method of paired comparison as described above, resulted in a raw data showing the proportion of times each research task was judged of more value than each other research task. These data were arranged in a square n x n matrix as shown in table 14. The diagonal of the matrix is blank, as indicated by the double asterisk, since research tasks were not compared with themselves. It should be pointed out that although some authors recommend completing the diagonal with 50% (or 5.5 in our case) instead of zeros, zeros are normally used. In the matrix of table 14, the numbers shown are the number of votes (out of 11 possible) that each research task in the matrix rows received when compared with those in the matrix columns. The columns are in the same order as the rows. As an example, consider row number 7 and column number 40. The research task in row 7 is FM-4, Measure Control Effectiveness. The research task in column 40 is SM-13, Heat Shield Instrumentation Sensor Studies. In this case, 9 out of 11 votes were for FM-4 indicating that 9 out of the 11 subjects considered FM-4 of more value than SM-13 when judged against the previously mentioned five attributes. Using Torgenson's terminology, this matrix is referred to as the F matrix. The next step in reducing this data is to construct matrix P from matrix F. The elements in matrix P are the observed proportion of times research tasks in rows were judged of more value than those in the columns.

TABLE 13

SINGLE SUBJECT VOTING MATRIX

		SM-11	FM-6	SM-17	PP-2	HF-2	FM-4	SM-13	GN-7	FM-16	SM-6	SM-16	SM-15	PP-3	FM-18	GN-3	SM-14	FC-4	AV-1	FM-2	PP-1	SM-3	FM-5	FM-8	HF-1	SM-18	SM-12	FM-15	FC-2	FM-19	FM-9	SM-10	SM-9	SM-8	GN-2	FC-1	GN-1	GN-6	FM-13	FM-3	FM-14	SM-7	FM-7	FM-12	SM-5	SM-1	AV-2	SM-2	EV-2	FM-17	GN-5	FC-3	GN-4
Inertial Navigation Error Propagation	GN-4	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	1	0	1	0	0	0	0	
Digital Flight Control Mechanization	FC-3	0	0	0	1	0	1	1	0	0	1	0	0	0	0	1	0	1	0	1	1	1	1	1	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1	1	0	1	1	0	0	1	0	1	1	1	1		
Hypersonic Entry Guidance Techniques	GN-5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	0	0	1	0	0	1	0	1	1	1			
Hypersonic Boundary Layer Transition	FM-17	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	0	0	1	0	0	1	0	1	0				
Evaluate Reuse Capability and Refurbishment Requirements	EV-2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	1	0	0	1	0	0	1	0	1					
Ablative Heat Shield Joints	SM-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0						
Satellite Communication Expt	AV-2	1	0	1	1	0	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	1	0	0	0	0	1	0	0	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1							
Ablative Heat Shield Performance and Analysis Correlation	SM-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
Insulation Cavity Pressure	SM-5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0									
Boundary Layer Survey	FM-12	1	0	1	1	0	1	1	0	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1										
Measure Pre ssure Distribution	FM-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0											
Ablator Ascent Heating-Cold Soak and Subsequent Entry	SM-7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0												
Viscous Effects on Lift and Drag	FM-14	0	0	1	1	0	1	0	1	0	1	0	0	0	0	1	1	0	0	1	1	1	1	1	0	0	0	0	1	0	0	1	0	1	1	1	1	1	1	1													
Evaluate Flying Qualities	FM-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0														
Ablation Effects on Hypersonic Aero	FM-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1															
Terminal Navigation and Guidance	GN-6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1																
Primary Navigation and Guidance Performance	GN-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
Flight Control System Evaluation	FC-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0																		
Backup Guidance System Performance	GN-2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0																			
Refurbishable Heat Shield Demonstration	SM-8	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0																				
Radiation Heat Shields	SM-9	1	0	0	1	0	1	1	1	1	1	0	0	0	0	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0																					
Radiative and Radiative to Ablative Heat Shield Joints	SM-10	1	0	0	1	0	1	1	1	1	1	0	1	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0																						
Measure Gas Cap Radiation Heat Transfer	FM-9	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																							
Synergetic Maneuver Simulation Without Thrust	FM-19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1																								
Adaptive Flight Control System	FC-2	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	0	0																									
Measure Plasma Thermophysics	FM-15	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	0																										
Ablator Over Coat on Radiation Panels	SM-12	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1	1	0	0	1	1	1	1	1	0	0																											
Inflight Heat Shield Repair	SM-18	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	0																												
Pilot Control/Landing of Vehicle After Prolonged Zero G	HF-1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1																													
Measure Heat Rate Distribution	FM-8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																														
Measure Elevon Shock Interaction	FM-5	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0																															
Ablator Materials Comparison	SM-3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0																																
Reaction-Jet Impingement Effects	PP-1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1																																	
Evaluate Aero Characteristics	FM-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																		
Antenna Window Material Test	AV-1	1	1	1	1	0	1	0	1	0	1	0	0	0	0	1	0	0																																			
Flight Control Actuation	FC-4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0																																				
After Heat Effects	SM-14	1	1	1	1	0	1	0	1	0	1	0	0	0	0	0																																					
Autonomous Orbital Navigation	GN-3	0	1	1	1	0	1	1	1	0	1	0	0	0	0																																						
Use of Ventral Antenna to Alleviate Communication Blackout	FM-18	1	1	1	1	0	1	1	1	1	1	0	0	0																																							
Landing Assist Propulsion	PP-3	1	1	1	1	1	1	1	1	1	1	1	1																																								
Transpiration Cooling System	SM-15	1	1	1	1	0	1	1	1	1	1	0																																									
Catalytic Wall Experiments	SM-16	1	1	1	1	0	1	1	1	1	1																																										
Movable Surface Heat Shield Design Problems	SM-6	0	0	0	0	0	1	0	0	0																																											
Effects of Electrophilic Fluid Injection	FM-16	0	0	1	1	0	1	1	1																																												
Air Data Measurements	GN-7	0	0	0	0	0	1	0																																													
Heat Shield Instrumentation Sensor Studies	SM-13	0	0	0	0	0	1																																														
Measure Control Effectiveness	FM-4	0	0	0	0	0																																															
Obtain Crew Bio-Medical Data Throughout Flight	HF-2	1	1	1	1																																																
Reaction Jet - Vehicle Boundary Layer Interaction	PP-2	0	0	1																																																	
Ascent Static and Dynamic Response-Des Crit Determination	SM-17	0	0																																																		
Measure Entry Stability and Control at Various CG Locations	FM-6	0																																																			
Active and Passive Structural Cooling	SM-11																																																			

Code

0 = column task not better than row task

1 = column task better than row task (e.g., SM-11 not better than GN-4)

TABLE 14

ALL SUBJECTS VOTING MATRIX

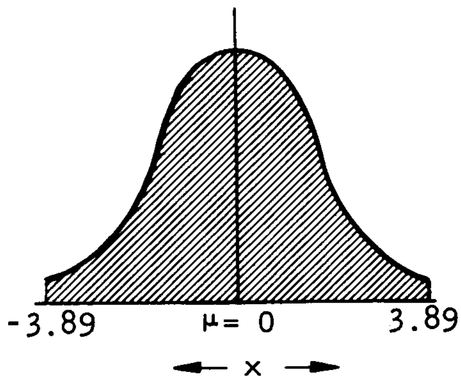
```
RANKED DATA MATRIX  11 SUBJECTS
                             10         20         30         40         50

 1  SM-1   ** 9 9 61011 910 9 910 9 911111111011101111111101111101111111111111111111110111111111111111111111111111111
 2  FM-8    2** 3 211 9 8 9 910 9 4 6 91011 9101010111111111111111110 91111101111111111111111101111111111111111111111111
 3  FM-3    2 8** 8 9101010 91010 7 91011 910111011111111111111101110111010101111111111101111111111111011111111101111111111
 4  FM-2    5 9 3** 911 910101110 6 810111110111011101111101111111111111111101011101010111110111010111111101111111111
 5  FM-7    1 0 2 2** 5 7 8 9 9 6 3 5 810 9 8 8 8101110111010101010111111101110111010111111111111111111111111111111
 6  GN-4    0 2 1 0 6** 3 7 5 5 5 3 1 5 7 7 5 4 9 8 8 9 81110 6 710111010 910 910 8 81110 9111111111111011111111111
 7  FM-4    2 3 1 2 4 8** 7 8 8 7 3 4 7 8 7 6 7 9 910 911 9 911 91010 9 9 9 910111011101 9101110101111 911101010
 8  GN-5    1 2 1 1 3 4 4** 5 7 4 4 4 5 4 5 4 8 7 6 9 7 8 910 71010101011 91110 9 910 9111010101011111111011111111
 9  FM-13   2 2 2 1 2 6 3 6** 6 5 3 3 6 6 6 4 6 8 6 7 8 8 9 9 9 8 911 9111010 9 8 910 91110101110101011111111111011
10  FM-5    2 1 1 0 2 6 3 4 5** 6 2 2 4 4 7 7 4 6 7 7 6 8 91110 5 9 8 9 7 9 811 7 71011 81011101111 91111111111111
11  EV-2    1 2 1 1 5 6 4 7 6 5** 3 2 5 7 6 7 5 9 8 6 8 810 8 8 810 910 91010101110 911 911101010111011101111101111
12  GN-1    2 7 4 5 8 8 8 7 8 9 8** 9 8 9 8 8 9 8101010 910101010 910 9101110 91010 91010 91011101010101010101010
13  FC-1    2 5 2 3 610 7 7 8 9 9 2** 8 7 9 8 9 81010 9 910101010 9 9 8101110 91011101010 91011101010101010101010
14  SM-6    0 2 1 1 3 6 4 6 5 7 6 3 3** 5 7 4 8 8 6 8 7 8 9 710 710 9 910 8 8 9 8 91110 911 910111010 911 911101010
15  SM-2    0 1 0 0 1 4 3 7 5 7 4 2 4 6** 7 5 6 8 7 8 7 8 9 8 7 7 9 9 9101010 811 91010 9 911 91010111110111101011
16  FM-17   0 0 2 0 2 4 4 6 5 4 5 3 2 4 4** 3 4 7 8 6 7 810 9 8 7 910 910 8 9 8 8 81010111010 910101011111011111110
17  SM-8    1 2 1 1 3 6 5 7 7 4 4 3 3 7 6 8** 5 9 8 9 5 81010 910 910 91010101010 9 9 91010101010 910101010 9101010
18  GN-6    0 1 0 0 3 7 4 3 5 7 6 2 2 3 5 7 6** 7 9 7 6 61010 9 6 910 8 910 8 9 7 91010 9 9 91010 91010101010 910
19  FM-14   1 1 1 1 3 2 2 4 3 5 2 3 3 3 3 4 2 4** 5 4 6 5 9 7 6 7 7 7 8 6 9 7 8 6 8 5 7 910 7 7 9 7 9 91011 9101011
20  GN-2    0 1 0 0 1 3 2 5 5 4 3 1 1 5 4 3 3 2 6** 7 3 7 7 7 6 6 7 7 7 8 9 7 8 7 8 9 910 8 810 9 8 9 910 91010 9 9
21  SM-17   0 0 0 1 0 3 1 2 4 4 5 1 1 3 3 5 2 4 7 4** 5 7 6 7 9 5 7 6 7 6 7 7 8 910 8 7 8 81010 9 8 910 9 9 9 910 9
22  SM-7    0 0 0 0 1 2 2 4 3 5 3 1 2 4 4 4 6 5 5 8 6** 5 6 7 7 7 7 8 7 8 8 8 7 7 9 7 7 8 8 8 8 8 9 9 7 8 9 8 91010
23  SM-5    1 0 0 0 0 3 0 3 3 3 3 2 2 3 3 3 3 5 6 4 4 6** 7 7 6 6 7 6 6 8 6 8 7 6 8 7 8 910 9 8 8 810 910 910101110
24  SM-9    0 0 0 1 1 0 2 2 2 2 1 1 1 2 2 1 1 1 2 4 5 5 4** 4 5 6 5 8 6 7 9 7 8 5 6 6 9 8 7 8 7 9 8 8 81011 9101111
25  SM-3    0 0 0 0 1 1 2 1 2 0 3 1 1 4 3 2 1 1 4 4 4 4 4 7** 7 7 8 7 7 9 7 8 7 7 9 9 8 610 8 91010 9 8 9 910101011
26  FM-6    1 0 1 0 1 5 0 4 2 1 3 1 1 1 4 3 2 2 5 5 2 4 5 6 4** 5 9 6 7 4 6 7 5 6 6 7 5 3 9 8 9 9 8 6 71010 7101011
27  GN-3    0 0 0 0 1 4 2 1 3 6 3 1 1 4 4 4 1 5 4 5 6 4 5 5 4 6** 8 4 9 8 7 7 7 6 9 7 6 7 7 8 9 9 9 910 8 7 710 9 8
28  FM-12   0 1 1 0 1 1 1 1 2 2 1 2 2 1 2 2 2 2 4 4 4 4 4 6 3 2 3** 5 4 6 8 6 8 5 9 8 7 6 8 7 6 8 8 8 8 810 71010 9
29  FC-2    0 2 0 0 0 0 1 1 0 3 2 1 2 2 2 1 1 1 4 4 5 3 5 3 4 5 7 6** 4 4 6 7 7 5 6 8 6 7 8 8 71010 8 911 810111110
30  FC-3    0 0 1 0 0 1 2 1 2 2 1 2 3 2 2 2 2 3 3 4 4 4 5 5 4 4 2 7 7** 5 7 5 6 5 7 7 7 7 5 8 5 9 9 8 8 9 8 9101010
31  GN-7    0 0 1 0 0 1 2 0 0 4 2 1 1 1 1 1 1 2 5 3 5 3 3 4 2 7 3 5 7 6** 5 6 6 7 9 7 6 711 5 8 8 7 8 8 9 710 810 9
32  PP-3    0 1 1 1 1 2 2 2 1 2 1 0 0 3 1 3 1 1 2 2 4 3 5 2 4 5 4 3 5 4 6** 2 5 3 7 8 5 6 9 5 7 9 7 6 8 7 7 7 7 7 9
33  FC-4    0 0 0 1 0 1 2 0 1 3 1 1 1 3 1 2 1 3 4 4 4 3 3 4 3 4 4 5 4 6 5 9** 6 6 8 8 6 5 7 6 7 8 6 9 8 8 8 9 9 8 9
34  FM-15   0 0 0 0 1 2 1 1 2 0 1 2 2 2 3 3 1 2 3 3 3 4 4 3 4 6 4 3 4 5 5 6 5** 3 6 7 6 6 7 6 610 7 8 9 9 6 8 91010
35  SM-14   0 0 0 1 0 1 0 2 3 4 0 1 1 3 0 3 1 4 5 4 2 4 5 6 4 5 5 6 6 6 4 8 5 8** 7 6 7 8 8 8 6 9 9 9 8 9 8 8 8 8 9
36  HF-2    1 0 0 1 1 3 1 2 2 4 1 1 0 2 2 3 2 2 3 3 1 2 3 5 2 5 2 2 5 4 2 4 3 5 4** 5 5 5 3 5 7 6 7 8 5 5 6 6 6 8 7
37  PP-2    0 0 1 1 1 3 0 1 1 1 2 2 1 0 1 1 2 1 6 2 3 4 4 5 2 4 4 3 3 4 4 3 3 4 5 6** 6 4 4 9 6 6 6 5 6 6 8 6 7 7 8
38  SM-10   0 0 0 0 0 0 1 2 2 0 0 1 1 1 1 1 2 1 4 2 4 4 3 2 3 6 5 4 5 4 5 6 5 5 4 6 5** 5 7 8 6 8 9 9 6 910 9 91110
39  SM-12   0 0 0 0 0 1 1 0 0 3 2 1 1 2 2 0 1 2 2 1 3 3 2 3 5 8 4 5 4 4 4 5 6 5 3 6 7 6** 8 6 6 8 810 7 8 8101110 8
40  SM-13   0 1 0 1 0 2 2 1 1 1 0 2 2 0 2 1 1 2 1 3 3 3 1 4 1 2 4 3 3 6 0 2 4 4 3 8 7 4 3** 4 5 5 5 5 4 7 6 5 8 810
41  PP-1    0 0 0 0 0 0 1 1 1 0 1 1 1 2 0 1 1 2 4 3 1 3 2 3 3 3 3 4 3 3 6 6 5 5 3 6 2 3 5 7** 5 9 6 7 6 7 8 9 8 8 7
42  SM-11   0 0 0 1 0 0 0 1 0 1 1 0 0 1 2 2 1 1 4 1 1 3 3 4 2 2 2 5 4 6 3 4 4 5 5 4 5 5 5 6 6** 7 8 7 310 6 7 7 8 8
43  SM-16   0 0 1 1 0 0 1 1 1 0 1 1 1 0 1 1 1 1 2 2 2 3 3 2 1 2 2 3 1 2 3 2 3 1 2 5 5 3 3 6 2 4** 6 5 5 3 6 5 6 5 8
44  AV-2    0 0 0 0 0 0 1 0 1 0 0 1 1 1 1 1 2 2 4 3 3 2 3 3 1 3 2 3 1 2 4 4 5 4 2 4 5 2 3 6 5 3 5** 5 6 2 8 7 6 8 9
45  HF-1    0 0 0 0 0 0 0 0 0 1 2 1 1 1 1 0 1 1 1 2 2 2 2 1 3 2 5 2 3 3 3 3 5 2 3 2 3 6 2 1 6 4 4 6 6** 5 6 8 6 7 8 8
46  FM-16   0 0 0 0 0 1 0 0 0 0 0 1 1 2 0 0 1 1 2 2 1 4 2 3 3 4 1 3 2 3 3 3 3 2 3 6 5 5 4 7 5 8 6 5 6** 6 5 7 8 8 8
47  SM-15   0 0 1 1 0 0 0 0 0 0 1 1 1 0 1 0 1 1 1 1 2 3 1 1 2 1 3 3 0 2 2 4 3 2 2 6 5 2 3 4 4 1 8 9 5 5** 8 6 6 6 8
48  FM-9    0 0 0 0 0 0 2 1 0 0 0 1 1 2 0 1 1 1 0 2 2 2 2 0 2 1 4 1 3 3 4 4 3 5 3 5 3 1 3 5 3 5 5 3 3 6 3** 5 7 6 8
49  AV-1    0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 2 1 2 1 2 3 1 2 1 4 4 4 1 2 1 4 2 3 3 5 5 2 1 6 2 4 6 4 5 4 5 6** 7 7 7
50  FM-18   0 0 0 0 0 0 1 0 0 0 1 1 1 1 1 0 1 1 1 1 2 2 1 1 1 1 1 1 0 1 3 4 2 2 3 5 4 2 0 3 3 4 5 5 4 3 5 4 4** 6 6
51  SM-18   0 0 0 0 0 0 1 0 1 0 0 1 1 1 1 0 1 2 1 2 1 1 0 0 1 1 2 1 0 1 1 4 3 1 3 3 4 0 1 3 3 3 6 3 3 3 5 5 4 5** 5
52  FM-19   0 0 0 0 0 0 1 0 0 0 0 1 1 1 0 1 1 1 0 2 2 1 1 0 0 0 3 2 1 1 2 2 2 1 2 4 3 1 3 1 4 3 3 2 3 3 3 3 4 5 6**
```

Normally having matrix P, it is now a simple matter to construct matrix X. The elements in matrix X are the unit normal deviate corresponding to the elements of the P matrix and may be found simply by referring to a table of areas under the unit normal curve. In the case under study, however, a complication arises. It will be noted that there is a significant number of 11 to 0 and 0 to 11 votes in the matrix of table 14. In the P matrix, these would reduce to proportions of 1.00 and 0.00, respectively, which cannot be used since the values for the X matrix corresponding to these proportions are unboundedly large. Normally when this situation is encountered, the cells in the X matrix, corresponding to the cells in the P matrix having 1.00 or 0.00 proportions, are left vacant and analytical techniques for incomplete X matrix are employed. In this case, due to the small sample size, there is a significant number of these cases, and it was felt the analysis would not be meaningful if all these data were discarded. To solve this dilemma, a truncated distribution, approximating the normal distribution, was developed so that the 1.00 and 0.00 proportions could be used. A distribution of the form shown in the following sketch was developed by truncating the normal distribution at 3σ units and then forcing the area under the curve to be equal to 1.

Thus, the distribution of the form $f(x) = ae^{-bx^2}$ where $-3.89 \leq x \leq -3.89$ and

$$\int_{-x}^{x} f(x)\, dx = 1$$

Using this distribution, the unit deviate values corresponding to the observed preportions are shown in table 15.



Derived Distribution Curve

TABLE 15

UNIT DEVIATE VALUES CORRESPONDING TO OBSERVED PORPORTIONS FOR TRUNCATED DISTRIBUTION

Observed proportions	Unit deviate value
0/11	- 3.8900
1/11	- 1.1204
2/11	- .7645
3/11	- .5094
4/11	- .2930
5/11	- .0963
6/11	.0963
7/11	.2930
8/11	.5094
9/11	.7645
10/11	1.1204
11/11	3.8900

With this technique, the X matrix will be complete and the usual analytical procedure for a complete matrix can be used. Mostellar (ref. 2) has shown that this usual procedure is a least squares solution and can be obtained simply by averaging the rows of the X matrix.

When using this technique and either the normal curve or the truncated distributions discussed herein, the final resulting scale will contain negative as well as positive values. Normally when using this technique to establish a scale, for instance, likes and dislikes, this presents no problem because the negative values can be interpreted to mean "disliked" items while positive numbers represent "liked" items. In this case though, negative values on research tasks have no meaning. Torgenson shows that the scale values derived through the law of comparative judgment locate the research tasks on a sensation scale with respect to one another only and that the zero point must be chosen arbitrarily. The method cannot determine an absolute zero point, thus determines values to within a linear constraint of the type $y = ax + b$. In this case though, it is desirable to express the value of the research tasks in relation to a rational rather than arbitrary zero point: that is to determine the scale values to within a linear transformation of the form $y = ax$. The technique for accomplishing this was a straightforward simple assessment of the effects of shifting the scale so that all research tasks would have positive value.

Many ways of shifting the scale were discussed but the only way that consistently seemed to make sense was to shift the scale sufficiently to make the lowest valued task equal to unity. Before this choice was finalized an assessment was made of the effects it would have on the decision making process of which this scale would become a part. As is shown in Part VI of this report a shift of this magnitude would have no discernable impact on the conclusions reached. Thus it was agreed to follow this technique (i.e., shifting the scale to make the value of the lowest valued task equal to unity).

F. COMPUTER PROGRAM AND RESULTS

A data analysis computer program was prepared to evaluate the results of the method of paired comparison. This program, written in FORTRAN IV for the IBM 1130 computer, accepts the individual raw data from each subject in the form shown in table 13. Using equations for the Torgenson Class II, condition C, representation of the Law of Comparative Judgment, the program calculates a linear value scale. Table 16 shows the resulting intrinsic value for the 52 research tasks using the paired comparisons of the 11 subjects. Figure 4 presents a plot of this data wherein each research task is positioned over its intrinsic value. The shading of the bubble for each experiment designates the requirement for man's participation in that experiment during the flight.

TABLE 16

RESEARCH TASK VALUE SCALE

Rank	Task	Value	Title
1	SM-1	237.1	Ablative Heat Shield Performance and Analysis Correlation
2	FM-8	215.9	Measure Heat Rate Distribution
3	FM-3	213.1	Evaluate Flying Qualities
4	FM-2	212.9	Evaluate Aero Characteristics
5	FM-7	183.6	Measure Pressure Distribution
6	GN-4	145.1	Inertial Navigation Error Propogation
7	FM-4	144.7	Measure Control Effectiveness
8	GN-5	142.7	Hypersonic Entry Guidance Techniques
9	FM-13	139.2	Ablation Effects on Hypersonic Aero.
10	FM-5	138.9	Measure Elevon Shock Interaction
11	EV-2	138.2	Evaluate Reuse Capability and Refurbishment Requirements
12	GN-1	134.0	Primary Navigation and Guidance Performance
13	FC-1	133.4	Flight Control System Evaluation
14	SM-6	120.3	Movable Surface Heat Shield Design Problems
15	SM-2	119.6	Ablative Heat Shield Joints
16	FM-17	114.9	Hypersonic Boundary Layer Transition
17	SM-8	113.8	Refurbishable Heat Shield Demonstration
18	GN-6	98.7	Terminal Navigation and Guidance Techniques
19	FM-14	96.6	Viscous Effects on Lift and Drag
20	GN-2	83.9	Backup Guidance Performance
21	SM-17	79.6	Ascent Static and Dynamic Response-Des Crit Determination
22	SM-7	79.3	Ablator Ascent Heating-Cold Soak and Subsequent Entry
23	SM-5	78.7	Insulation Cavity Pressure
24	SM-9	77.4	Radiation Heat Shields
25	SM-3	75.2	Ablator Materials Comparison
26	FM-6	74.8	Measure Entry Stability and Control at Various C. G. Location
27	GN-3	73.9	Autonomous Orbital Navigation
28	FM-12	70.8	Boundary Layer Survey
29	FC-2	70.6	Adaptive Flight Control System
30	FC-3	66.6	Digital Flight Control Mechanization
31	GN-7	61.5	Air-Data Measurements
32	PP-3	60.3	Landing Assist Propulsion
33	FC-4	59.8	Flight Control Actuation
34	FM-15	59.4	Measure Plasma Thermophysics
35	SM-14	58.5	After Heat Effects
36	HF-2	55.2	Crew Bio-Medical and Performance Monitoring

TABLE 16--Concluded

Rank	Task	Value	Title
37	PP-2	53.2	Jet Exhaust/Vehicle Boundary Layer Interactions
38	SM-10	52.1	Radiative and Radiative to Ablative Heat Shield Joints
39	SM-12	51.9	Ablator Over Coat on Radiative Heat Shields
40	SM-13	43.2	Heat Shield Instrumentation Sensor Studies
41	PP-1	40.9	Jet Impingement Effects and Analytical Correlation
42	SM-11	37.5	Active and Passive Structural Cooling
43	SM-16	34.7	Catalytic Wall Experiments
44	AV-2	31.7	Satellite Communication Experiment
45	HF-1	30.7	Pilot Control/Landing of Vehicle After Prolonged Zero G
46	FM-16	25.0	Effects of Electrophilic Fluid Injection
47	SM-15	21.7	Transpiration Cooling System
48	FM-9	18.9	Measure Gas Cap Radiation Heat Transfer
49	AV-1	13.1	Antenna Window Material Test
50	FM-18	12.5	Use of Ventral Antenna to Alleviate Communication Blackout
51	SM-18	5.0	Inflight Heat Shield Repair
52	FM-19	1.0	Synergetic Maneuver Simulation Without Thrust

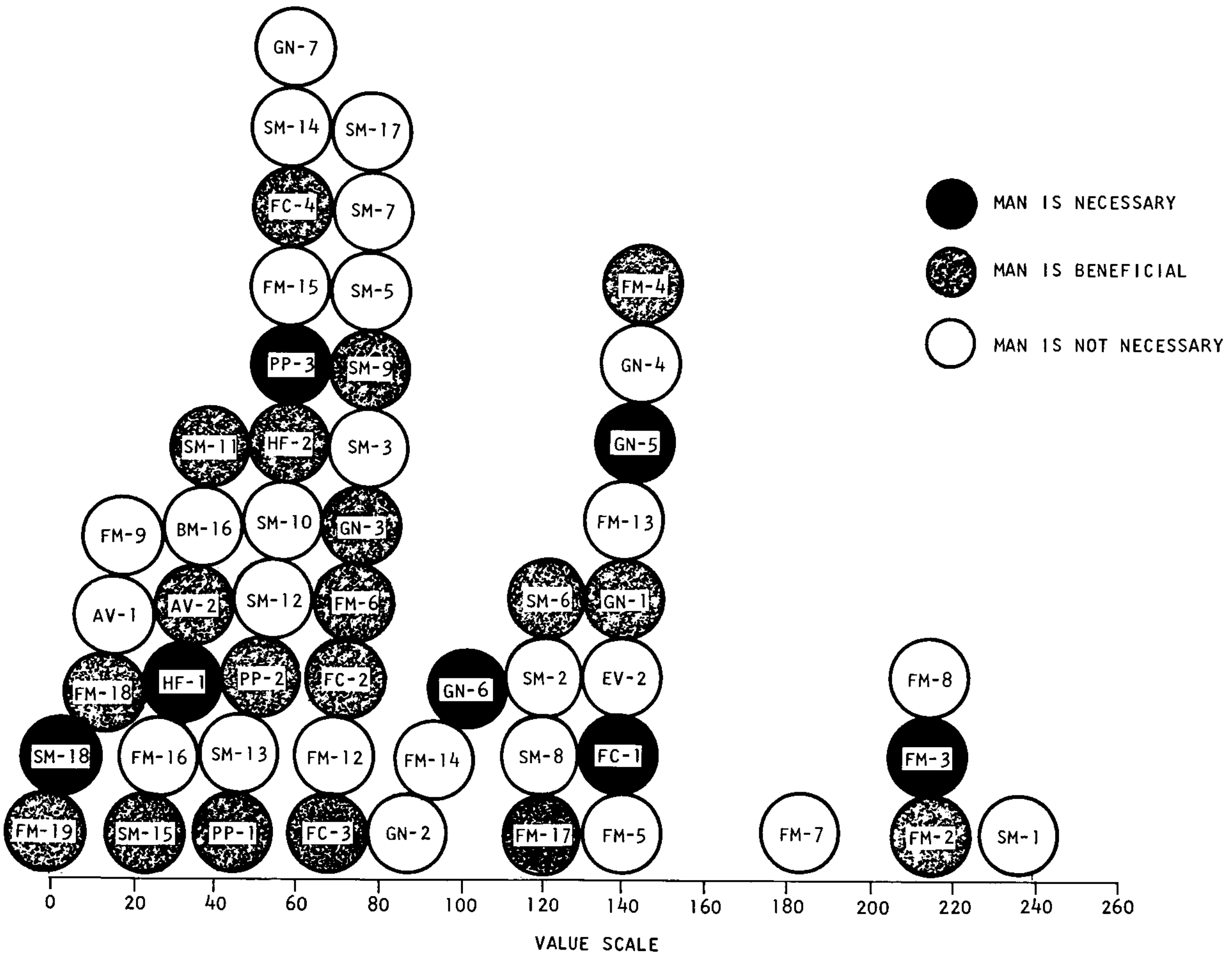


FIGURE 4. RESEARCH TASK VALUE DISTRIBUTION

PRECEDING PAGE BLANK NOT FILMED.

VII. BASELINE FLIGHT TEST TASKS

These baseline-type tasks are listed separately because of their requirement in support of the flight program independent of the research tasks. They will not be ranked or given values but will be appropriately loaded in the flight plan prior to loading of the research tasks.

Whenever a new configuration operates under unique environmental conditions, tasks such as those included in this section must be performed. The specific reason for performing each task is listed below:

	Task Description	Justification
PP-6	Demonstrate Deorbit Propulsion Sequence	Required before manned flight for crew safety
SM-19	Evaluate Visibility During Flight Phase	Data needed to ascertain visibility problems during extreme conditions
EV-1	Demonstrate Subsystem Performance	Data, only obtainable in actual flight, needed for safety and performance margin confirmation
FM-1	Launch Vehicle Compatibility	Total system performance in true environment
FM-20	Entry Vehicle Basic Attitude, Flight Path and Environment	Basic data needed to support all aerodynamic and guidance-navigation tasks
BI-4	Demonstrate Performance of Ground Operating Systems	Evaluates support effectiveness
BL-10	High Altitude Pre-injection Abort	Demonstrate crew safety before manned flight
BL-11	Evaluate Landing Slide-out Characteristics	Evaluation of landing gear after exposure to entry environment--no previous experience

RESEARCH TASK SUMMARY

BASELINE FLIGHT TEST TASKS	Category			Missions								Phase				Man			Work Statement	
	Verification Confirmation	Technology Advance	Pure Research	MORL-Logistics	Rescue	Reconnaissance	Satellite Inspection	MOL-Logistics	Sat. Repair	Lunar Expl	Mars Fly-By	Ascent	Orbit	Return	Ground	Integral Part	Contributions	No Value	Primary	Secondary
SM-19 Evaluate visibility during terminal flight phase	X			X	X	X	X	X	X					X		X			X	
PP-6 Demonstrate deorbit propulsion sequence	X			X	X	X	X	X	X					X			X		X	
EV-1 Demonstrate subsystem performance	X			X	X	X	X	X	X			X	X	X				X	X	
FM-1 Launch vehicle compatibility	X			X	X	X	X	X	X			X						X	X	
FM-20 Entry vehicle basic altitude environment and flight path	X			X	X	X	X	X	X	X	X	X	X	X			X		X	
BL-4 Demonstrate performance of ground operating systems	X			X	X	X	X	X	X	X	X	X	X	X			X		X	
BL-10 High altitude preinjection abort	X			X	X	X	X	X	X	X	X			X				X	X	
BL-11 Evaluate landing slideout characteristics	X			X	X	X	X	X	X					X			X		X	

BASELINE FLIGHT TEST TASK

TASK TITLE	
Evaluate Visibility During Terminal Flight Phase	TASK NO. SM-19 VALUE NA

OBJECTIVE

Assessment of pilot's visibility below 100,000 ft for future research application; to demonstrate canopy and auxiliary optics sequencing and performance under real environment.

DESCRIPTION

(1) Monitor EV attitude (3 axes) and coordinates relative to landing point during terminal phase (100,000 ft altitude (30.5 km) to slide-out).

(2) Compute observable land area, horizon range, visible sector of runway from monitored data described above.

(3) Record and transmit pilot's evaluation of overall visibility throughout terminal flight and landing by voice comments.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable (terminal flight phase experiment).	Minimum of 2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
EV attitude	Inertial reference system	3
EV altitude	Ground tracking	-
EV coordinates relative to runway	Ground tracking	-
Pilot's comments	Voice to MCC/FRC (tape recorder)	-

AIRBORNE EQUIPMENT OTHER THAN SENSORS	
None	WEIGHT (LB) 0 POWER (WATT) 0

BASELINE FLIGHT TEST TASK

TASK TITLE	TASK NO. PP-6
Demonstrate Deorbit Propulsion Sequence	VALUE NA

OBJECTIVE

Establish high degree of confidence in deorbit system prior to manned flight.

DESCRIPTION

(1) Initiate attitude and retrofire by ground command update

(2) Monitor deorbit performance parameters

(3) Establish initial entry conditions obtained by on-board guidance and ground track

(4) Monitor RCS thrusting history

(5) Ripple fire four motors in at least one flight.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable.	All unmanned flights

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Retrofire attitude	Inertial reference system	6
Time to retrofire	Pressure transducer	2
Orbital ephemeris	Ground tracking	-
Retroburn time	Pressure transducer	2
Electrical sequences	-	-
RCS thrusting history	Pressure transducer	6

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
None	0	0

BASELINE FLIGHT TEST TASK

TASK TITLE	TASK NO. EV-1
Demonstrate Subsystem Performance (primary and backup)	VALUE NA

OBJECTIVE

Evaluate subsystem performance relative to specified performance and to determine potential application limits for future flights.

DESCRIPTION

(1) Measure subsystem performance during launch, orbit, deorbit, entry and landing.
(2) Determine subsystem performance margins for critical functions.
(3) Compare measured performance with specified values and determine margins.
(4) Initiate modifications and/or flight restrictions if required.

Applicable Primary and Secondary Subsystems

Navigation and Guidance	EC/LS
Electronic Flight Controls	RCS
Instrumentation and T/M	Crew Systems
Electrical Power	Canopy Cover
Control Surfaces	Landing

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable.	2 unmanned Minimum of 1 manned

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
System signals	-	Total approximately 250
Flows and flow rates	Flowmeters	
Voltage and current	-	
Power	-	
Temperature	Thermocouples	
Load	Load cells	
Position	Linear displacement gage	
Pressure	Pressure transducers	
Dynamic response	Accelerometers	

AIRBORNE EQUIPMENT OTHER THAN SENSORS		WEIGHT (LB)
Metabolic simulators	Programmers	0
Command decoders	Cameras	POWER (WATT) 0

TASK TITLE	TASK NO. FM-1
Launch Vehicle Compatibility	VALUE NA

OBJECTIVE

To demonstrate launch vehicle performance with the entry vehicle and adapter.

DESCRIPTION

(1) Demonstrate LV performance and flight qualify all LV systems.
(2) Determine exit heating conditions on EV, LV and adapter.
(3) Demonstrate structural integrity and compatibility of the EV, LV and adapter.
(4) Demonstrate accurate orbit insertion.
(5) Demonstrate operation of malfunction detection system and exercise switch-over if necessary.
(6) Demonstrate launch system countdown compatibility.
(7) Demonstrate EV performance and flight qualify all EV subsystems as required for manned flight.
(8) Demonstrate EV separation from LV.
(9) Evaluate launch wind and gust environmental effects.
(10) Measure boundary layer noise induced vibration and EV backwash effects.
(11) Measure launch induced environments at crew positions.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable.	1 unmanned

MEASUREMENTS REQUIRED See attached sheet (page 207)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
None	0	0

MEASUREMENTS REQUIRED: FM-1		
PARAMETER	INSTRUMENTATION	NO. OF SENSORS
LV flight path and velocity	LV airborne guidance; ground track	-
LV attitude	LV inertial reference system	-
Exit heating	Thermocouples in EV	20
Structural loads	Strain gages	40
Vibration and sound pressure	Accelerometers; microphones	40
Static pressure	Pressure transducers	40
LV subsystem functions	Flow, temperature, pressure, signals	200
EV subsystem functions	Flow, temperature, pressure, signals	200
Air density, wind, temperature	Precision meteorological data	-

TASK TITLE	TASK NO. FM-20
Entry vehicle basic attitude, flight path and environment	VALUE NA

OBJECTIVE

To reconstruct entry trajectory, environment, vehicle attitude and angles of attack for entry research analysis.

DESCRIPTION

(1) Data acquisition includes on-board equipment, ground based systems, and sounding rocket launched equipment.

(2) Data is acquired from all sources, compiled and adjusted using statistical techniques, and published. Results used in reducing data obtained in various experiments.

FLIGHT CONDITIONS	NO. OF FLIGHTS
As determined by other tasks (supports all research tasks)	All flights

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Altitude	Ground tracking	
Velocity	Ground tracking; IRS	
Flight path angles	Ground tracking	
α, β, ϕ	Ground track plus IRS	
Attitude and rates	Inertial reference system	
Body axes acceleration	Accelerometers	
Atmospheric density	Meteorological data	
Atmospheric temperature	Meteorological data	
Wind profiles and gusts	Meteorological data	
Ionosphere intensities	Meteorological data	
Weather at landing sites	Meteorological data	

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
None	0	0

BASELINE FLIGHT TEST TASK

TASK TITLE	TASK NO. BL-4
Demonstrate Performance of Ground Operating Systems	VALUE NA

OBJECTIVE

Measure effectiveness of ground operating facilities and personnel in supporting manned flight research missions.

DESCRIPTION

(1) Conduct preflight exercises at MCC-Houston, KSC and FRC-Edwards.

a. Launch injection data--KSC to MCC via Goddard
b. Orbital tracking and telemetry data transmission and deorbit data
c. Entry tracking (stations to MCC)
d. Post blackout tracking (aircraft flyby)
e. FRC approach and landing flare (air drop vehicles)

(2) Evaluate accuracy and speed of data transfer (tracking and voice communication) and effectiveness of decisions during one unmanned and one manned flight.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable. Flight must include launch, orbit, entry and landing.	1 unmanned 1 manned (first)

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
1. Pilot's comments on quality and effectiveness of ground data	Voice-RF transmit and/or on-board record	One voice channel per crew member
2. Ground tracking	Ground computer output	-
3. Ground guidance commands (voice or coded)	Voice and/or signal	-
4. Trajectory hand-off data	Ground computer output	-

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
None	0	0

TASK TITLE	TASK NO. BL-10
High Altitude Preinjection Abort	VALUE NA

OBJECTIVE

(1) To demonstrate entry vehicle integrity and crew safety during high altitude abort.
(2) Demonstrate recovery system and water landing as specified.

DESCRIPTION

(1) Demonstrate adequacy of entry vehicle structure and controls during a maximum load factor and dynamic pressure entry.

(2) Demonstrate pitch modulation procedure for load factor limiting.

(3) Examine results for compatibility with psychological constraints of crew and structural limits.

(4) Demonstrate and measure recovery and water landing performance.

NOTE: This test conducted with special launch vehicle in suborbital flight.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Flight condition type A	1 (unmanned)

MEASUREMENTS REQUIRED See attached sheet (page 211)

PARAMETER	INSTRUMENTATION	NO. OF SENSORS

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
None	0	0

MEASUREMENTS REQUIRED: BL-10		
PARAMETER	INSTRUMENTATION	NO. OF SENSORS
L/D	IRS and accelerometers	6
α, β, ϕ	IRS; ground track; pressure	20
Velocity	IRS and ground track	6
Altitude	Ground tracking	-
Attitude	Inertial reference system	6
Structural stress	Strain gages	80
Hinge moments	Force transducers; hydraulic pressure	24
Aero static pressure	Pressure transducers	20
Subsystem diagnostic data	Signal, temperature, pressure, flow	100

BASELINE FLIGHT TEST TASK

TASK TITLE	TASK NO. BL-11
Landing Dynamics and Slideout Characteristics After Entry Exposure	VALUE NA

OBJECTIVE

To confirm touchdown loads and slideout characteristics previously obtained in air drop tests.

DESCRIPTION

(1) Execute nominal landing after entry flight.

(2) Measure slide-out path and velocities.

(3) Measure entry vehicle touchdown and slide-out dynamics.

(4) Measure pilot's control forces and reactions.

(5) Compare above results with air drop test results.

FLIGHT CONDITIONS	NO. OF FLIGHTS
Any entry condition is suitable	2

MEASUREMENTS REQUIRED

PARAMETER	INSTRUMENTATION	NO. OF SENSORS
Run-out distance	Photo theodolite	2
Lateral slide	Photo theodolite	2
Wind velocity and direction	Standard meteorological	-
EV approach heading	Photo, radar	1
EV final sinking speed	Photo theodolite; strut motion	4
EV touchdown attitudes	IRS signals	6
Skid strut loads	Strain gages	12
Skid wear	Postflight examination	-

AIRBORNE EQUIPMENT OTHER THAN SENSORS	WEIGHT (LB)	POWER (WATT)
None	0	0

REFERENCES

1. Torgerson, W. S., "Theory and Methods of Scaling," New York, John Wiley and Sons, Inc., (1958).

2. Mosteller, F. "Remarks on the Method of Paired Comparisons. I The Least Squares Solution Assuming Equal Standard Deviations and Equal Correlations," Psychometrika, Vol. 16, No. 1, March 1951.

3. FDL TDR 64-79, "Study of an Advanced Energy Management System for Re-entry Vehicles," prepared by Bell Aerosystems Company, September 1964.

4. "Feasibility Study, Minimum Manned Lifting Body Entry Vehicle," McDonnell Aircraft Corporation, Contract NAS 4-839, Vol. 1, 31 December 1965.

5. Tannas, L. E., Jr., "Entry Guidance Through Closed-Form Range Equations," AIAA/JACC Guidance and Control Conference, Seattle, Washington, August 15-17, 1966.

APPENDIX

RESEARCH TASK MEASUREMENT LIST

The following are the detailed measurement lists for the HL-10 research tasks, preceded by a summary of the data handling requirements for those tasks (table 17). Computed values of sample rates and bit rates were computed using the measurement list analysis program. For ease of understanding, the column headings on the measurement lists are herewith defined:

Item No.	Indicate commonality
Qty	Number of times this measurement is repeated for a particular task.
Measurement Type	A generic measurement description
Accuracy	Percent end-to-end accuracy required for this measurement, including sensor errors
Frequency Response	Description of the power spectral density of the measurement signal. For the purpose of selecting sample rates for this study, the number specified here was considered to be the corner frequency of a Bitterworth-shaped response with 24 db/octave rolloff.
SPS	Computed sample rate in samples per second
No. Bits	Number of bits per measurement
BPS	Computed bit rate in bits per second
Sensor	Generic sensor type for this measurement

TABLE 17

SUMMARY OF RESEARCH TASK DATA HANDLING REQUIREMENTS

	Number of analog measurements 1%	Number of analog measurements 2%	Number of analog measurements 5%	Number of analog measurements 10%	Number of digital measurements 1 bit	Number of digital measurements 4 bits	Number of digital measurements 5 bits	Number of digital measurements 14 bits	Number of digital measurements 18 bits	Total number of measurements	Bit rate (K bits/sec)	Bit rate ranking	Value ranking
Baseline	10	119	87				16	59		291	58.92	-	-
AV-1		18								18	4.44	46	46
FC-1	10	51	30		16			6		113	46.26	7	3
FC-2	10	51	30		16			6		113	46.26	8	38
FC-3	10	55	30		16			41		152	48.95	6	35
FC-4	10	20	19		16			6		71	26.26	21	36
FM-2	20		15							35	19.00	30	8
FM-3	30		37							67	45.00	9	4
FM-4	36		25							61	39.42	15	12
FM-5	70	30	10							110	26.35	20	22
FM-6	30		31							61	42.00	14	34
FM-7	160									160	59.50	5	6
FM-8		310								310	18.60	31	5
FM-9	26			1						27	17.60	32	50
FM-12	30	40								70	12.90	35	43
FM-13	100	135	54			10				299	83.21	2	18
FM-14	150	110	20							280	79.10	3	48
FM-15	50	86								136	43.90	11	24
FM-16	10	30								40	27.08	19	26
FM-17		80	60							140	44.90	10	25
FM-18		40	20			2				62	22.41	27	49
FM-19		170				20				190	10.28	39	51
GN-1	12		3					26	1	42	12.16	36	2
GN-2	12		3					45	1	61	13.49	34	16
GN-3	4	19						35	1	59	9.64	40	20
GN-4	12	15	3					74	1	105	20.02	28	27
GN-5	12	30	3					90	1	136	25.64	24	21
GN-6	15	39	3					90	2	149	30.53	18	23
GN-7	12	20	3					45	1	81	19.49	29	29
HF-1		4	10							14	5.24	44	39
HF-2		4	10							14	5.24	45	14
PP-1	20	67	6							93	42.88	12	37
PP-2		32	6							38	25.68	23	47
PP-3		3	3							6	2.85	48	40
SM-1		400				20				420	24.08	25	1
SM-2		40	40		20					100	42.42	13	11
SM-3	10	90				5				105	8.92	41	28
SM-5		40	20							60	7.40	43	17
SM-6	30	120	10							160	73.20	4	10
SM-7		100	20		40					160	26.04	22	7
SM-9		200	20							220	17.00	33	30
SM-9		50	20							70	8.00	42	30
SM-10		10	43							53	31.00	17	31
SM-11	10	110	6							126	10.40	38	33
SM-12		40			20					60	2.42	49	32
SM-13		15	12			8				35	38.13	16	45
SM-14		200								200	12.00	37	19
SM-15	35	125								160	23.25	26	41
SM-16	6	30								36	3.90	47	42
SM-17	50	84								134	97.52	1	9

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO.

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
0001-0015	14	Antenna Impedance	2	5.0	50.0	6	250.0	Phase Angle Detection
0016-0019	4	Antenna Window Temp	2	1.0	10.0	6	60.0	Thermocouples

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FC-1

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5009-5024	16	On Time of Reaction Control Thrusters	-	.1 sec	5.0	1	5.0	Solenoid Valve Signals
5252-5254	3	Elevon & Rudder Activator Positions	2	1.0	10.0	6	60.0	Control Surface Actuators
4000-4011	12	Hydraulic Control Actuator Loads	2	1.0	10.0	6	60.0	Pressure Transducers
5255-5260	6	Trim Surface Settings	2	1.0	10.0	6	60.0	Signal Transducers
7070-7072	3	Attitude Rate	5	10.0	100.0	5	500.0	FCS Rate Gyros
7100-7102	3	Accelerations	5	25.0	200.0	5	1000.0	Accelero-meters
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentio-meters
5003-5005	3	Attitude Primary IGS	-	.1 sec	5.0	14	70.0	Primary IGS Computer
6200-6223	24	Structural Response	5	25.0	200.0	5	1000.0	Accelero-meters
5231-5240	10	Air Data System	2	5.0	50.0	6	300.0	Air Data System
5000-5002	3	Guidance Commands From Primary IGS	-	.1 sec	5.0	14	70.0	Primary IGS

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FC-1

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5261-5280	20	FCS Diagnostic Signals	2	5.0	50.0	6	300.0	Analog FCS

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FC-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5009-5024	16	On Time of Reaction Control Thrusters	-	.1 sec	5.0	1	5.0	Solenoid Valve Signals
5252-5254	3	Elevon & Rudder Actuator Position	2	1.0	10.0	6	60.0	Control Surface Actuators
4000-4011	12	Hydraulic Control Actuator Loads	2	1.0	10.0	6	60.0	Pressure Transducers
5255-5260	6	Trim Surface Settings	2	1.0	10.0	6	60.0	Signal Transducers
7070-7072	3	Attitude Rate	5	10.0	100.0	5	500.0	FCS Rate Gyros
7100-7102	3	Accelerations	5	25.0	200.0	5	1000.0	Accelero-meters
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentio-meters
5003-5005	3	Attitude Primary IGS	-	.1 sec	5.0	14	70.0	Primary IGS Computer
6200-6223	24	Structural Response	5	25.0	100.0	5	500.0	Accelero-meters
5231-5240	10	Air Data System	2	5.0	50.0	6	300.0	Air Data System
5000-5002	3	Guidance Commands from Primary IGS	-	.1 sec	5.0	14	70.0	Primary IGS

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. FC-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5261-6280	20	FCS Diagnostic Signals	2	5.0	50.0	6	300.0	Analog FCS

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. FC-3

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5009-5024	16	On Time of Reaction Control Thrusters	-	.1 sec	5.0	1	5.0	Solenoid Valve Signals
5252-5254	3	Elevon & Rudder Actuator Positions	2	1.0	10.0	6	60.0	Control Surface Actuators
4000-4011	12	Hydraulic Control Actuator Loads	2	1.0	10.0	6	60.0	Pressure Transducers
5255-5260	6	Trim Surface Settings	2	1.0	10.0	6	60.0	Signal Transducers
7070-7072	3	Attitude Rate	5	10.0	100.0	5	500.0	FCS Rate Gyros
7100-7102	3	Accelerations	5	25.0	200.0	5	1000.0	Accelero-meters
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentio-meters
5003-5005	3	Attitude Primary IGS	-	.1 sec	5.0	14	70.0	Primary IGS Computer
6200-6223	24	Structural Response	5	25.0	200.0	5	1000.0	Accelero-meters
5231-5240	10	Air Data System	2	5.0	50.0	6	300.0	Air Data System
5000-5002	3	Guidance Commands From Primary IGS	-	.1 sec	5.0	14	70.0	Primary IGS

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FC-3

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5261-5280	20	FCS Diagnostic Signals	2	5.0	50.0	6	300.0	Analog FSC
5070-5104	35	FCS Diagnostic Digital Signals	-	.1 sec	5.0	14	70.0	Digital FCS System

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7179-7182	4	Aero Surface Press -Fore Body	1	2.0	50.0	7	350.0	Pressure Transducer
7229-7235	8	Aero Surface Press -After Body	1	2.0	50.0	7	350.0	Pressure Transducer
7110-7115	6	Aero Surface Press -Fins	1	2.0	50.0	7	350.0	Pressure Transducer
7120-7121	2	Aero Surface Press -Elevons	1	2.0	50.0	7	350.0	Pressure Transducer
7100-7108	9	Accelerations	5	25.0	200.0	5	1000.0	Accelerometers
7070-7075	6	Attitude Rates	5	10.0	100.0	5	500.0	Rate Gyros

HL-10 RESEARCH TASK
MEASUREMENT LIST TASK NO. FM-3

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensors
7140-7155	16	Control Surfaces Hinge Moments	5	25.0	200.0	5	1000.0	Load Cells
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentiometers
7179-7182	4	Aero Surface Press Forebody	1	2.0	50.0	7	350.0	Pressure Transducers
7229-7236	8	Aero Surface Press Afterbody	1	2.0	50.0	7	350.0	Pressure Transducers
7110-7115	6	Aero Surface Press Fins	1	2.0	50.0	7	350.0	Pressure Transducers
7120-7121	2	Aero Surface Press Elevons	1	2.0	50.0	7	350.0	Pressure Transducers
7100-7108	9	Accleration	5	25.0	200.0	5	1000.0	Accelerometer
7070-7075	6	Angular Rates	5	10.0	100.0	5	500.0	Rate Gyros
8001-8004	4	Electrocardiogram	5	12.0	100.0	5	500.0	Electrocardiograph
8005-8006	2	Blood Pressure	5	12.0	100.0	5	500.0	Syphgmomanometer
8007-8010	4	Respiratory Rate	5	12.0	100.0	5	500.0	Pneumograph
8011-8014	4	Body Temperature	2	1.0	10.0	6	60.0	Thermister

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FC-4

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentiometers
5000-5002	3	Guidance Error		.1 sec.	5.0	14	70.0	Guidance Computer
5003-5005	3	Vehicle Attitude		.1 Sec.	5.0	14	70.0	Guidance Computer
7070-7072	3	Vehicle Rate	1	0.0	10.0	.7	70.0	Rate Gyros
5009-5024	16	RCS Firing Times		.1 Sec	5.0	1	5.0	Solenoid Valve Signals
7140-7155	16	Hinge Moment (Control Surfaces)	5	25.0	200.0	5	1000.0	Load Cells
5025-5044	20	Component Temp.	2	1.0	10.0	6	60.0	Thermocouples

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-4

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensors
7140-7155	16	Control Surfaces Hinge Moments	5	25.0	200.0	5	1000.0	Load Cells
7034-7043	10	Control Positions	1	10.0	200.0	7	1000.0	Potentiometers
7100-7108	9	Accelerations	5	25.0	200.0	5	1000.0	Accelerometer
7070-7075	6	Vehicle Rater	5	10.0	100.0	5	500.0	Rate Gyros
7179-7182	4	Aero Surface Press Forebody	1	2.0	50.0	7	350.0	Pressure Transducer
7229-7232	4	Aero Surface Press Afterbody	1	2.0	50.0	7	350.0	Pressure Transducer
7120-7127	8	Aero Surface Press Elevons	1	2.0	50.0	7	350.0	Pressure Transducer
7156-7159	4	Aero Surface Press	1	2.0	50.0	7	350.0	Pressure Transducer

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-5

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7179-7198	20	Aero Surface Press --Fore Body	1	2.0	50.0	7	350.0	Pressure Transducer
7229-7258	30	Aero Surface Press --After Body	1	2.0	50.0	7	350.0	Pressure Transducer
7120-7139	20	Aero Surface Press --Elevons	1	2.0	50.0	7	350.0	Pressure Transducer
6020-6021	2	H.S. Temp -- Top	2	1.0	10.0	6	60.0	Thermocouples
6040-6041	2	H.S. Temp -- Sides	2	1.0	10.0	6	60.0	Thermocouples
6130-6145	16	H.S. Temp -- Elevons	2	1.0	10.0	6	60.0	Thermocouples
1739-1740	2	Heat Flux -- Fore Body	2	1.0	10.0	6	60.0	Calorimeter
1779-1786	8	Heat Flux -- After Body	2	1.0	10.0	6	60.0	Calorimeter
7300-7309	10	Boundry Layer	5	.1	1.0	5	5.0	Microphones

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-6

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7140-7155	16	Control Surfaces Hinge Moments	5	25.0	200.0	5	1000.0	Load Cells
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentiometers
7100-7108	9	Accelerations	5	25.0	200.0	5	1000.0	Accelerations
7070-7075	6	Vehicle Rates	5	10.0	100.0	5	500.0	Rate Gyros
7179-7182	4	Aero Surface Press Forebody	1	2.0	50.0	7	350.0	Pressure Transducers
7229-7232	4	Aero Surface Press Afterbody	1	2.0	50.0	7	350.0	Pressure Transducers
7110-7113	4	Aero Surface Press Fins	1	2.0	50.0	7	350.0	Pressure Transducers
7120-7123	4	Aero Surface Press. Elevons	1	2.0	50.0	7	350.0	Pressure Transducers
7156-7159	4	Aero Surface Press Rudders	1	2.0	50.0	7	350.0	Pressure Transducers

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. FM-7

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7171-7178	8	Aero Surface Pres. Nosecap	1	2.0	50.0	7	350.0	Pressure transducers
7179-7228	50	Aero surface pres. forebody	1	2.0	50.0	7	350.0	Pressure transducers
7229-7298	70	Aero surface press. afterbody	1	2.0	50.0	7	350.0	Pressure transducers
7110-7115	6	Aero surface press fins	1	2.0	50.0	7	350.0	Pressure transducers
7120-7127	8	Aero surface pres. elevons	1	2.0	50.0	7	350.0	Pressure transducers
7156-7163	8	Aero surface press. rudders	1	2.0	50.0	7	350.0	Pressure transducers
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentiometers

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-8

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1839-1858	20	Heat Flux -Fins and Rudder	2	1.0	10.0	6	60.0	Calorimeter
1859-1878	20	Heat Flux -Elevons	2	1.0	10.0	6	60.0	Calorimeter
6060-6074	15	Heat Shield Temp. -Leading Edge	2	1.0	10.0	6	60.0	Thermocouples
6095-6119	15	Heat Shield Temp. -Bottom	2	1.0	10.0	6	60.0	Thermocouples

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-9

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1879	1	Spectral Intensity	10	500.0	3200.0	4	12800.0	Spectrometer (Block Engineering Model E-8A)
1880-1885	6	Radiation Heat Flux	2	10.0	100.0	6	600.0	Radiometer
1886-1899	14	Radiation Temperature --Nose Cap	2	1.0	10.0	6	60.0	Thermocouple
1900-1905	6	Radiation Temperature --Fore Body	2	1.0	10.0	6	60.0	Thermocouple

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-8

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6005-6014	10	Heat Shield Temp. -Nose Cap	2	1.0	10.0	6	60.0	Thermocouple
6020-6034	15	Heat Shield Temp. -Top	2	1.0	10.0	6	60.0	Thermocouple
6040-6054	15	Heat Shield Temp. -Sides	2	1.0	10.0	6	60.0	Thermocouple
6130-6149	20	Heat Shield Temp. -Elevons	2	1.0	10.0	6	60.0	Thermocouple
6170-6189	20	Heat Shield Temp. -Fins	2	1.0	10.0	6	60.0	Thermocouple
6235-6254	20	Air Frame Temp. H.S. Panels	2	1.0	10.0	6	60.0	Thermocouple
6285-6304	20	Air Frame Temp. -Struct. Skin	2	1.0	10.0	6	60.0	Thermocouple
1719-1728	10	Temperature Gradients	2	1.0	10.0	6	60.0	Thermocouple
1729-1738	10	Heat Flux -Nose Cap	2	1.0	10.0	6	60.0	Calorimeter
1739-1778	40	Heat Flux -Fore Body	2	1.0	10.0	6	60.0	Calorimeter
1779-1838	60	Heat Flux -After Body	2	1.0	10.0	6	60.0	Calorimeter

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-12

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1906-1915	10	Pressure Rake	1	2.0	50.0	7	350.0	Pressure Transducer
7179-7186	8	Aero Surface Press -Forebody	1	2.0	50.0	7	350.0	Pressure Transducer
7229 7236	8	Aero Surface Press -Afterbody	1	2.0	50.0	7	350.0	Pressure Transducer
1916-1925	10	Temperature Rake	2	1.0	10.0	6	60.0	Thermocouples
6020-6024	5	Heat Shield Temp. -Top	2	1.0	10.0	6	60.0	Thermocouples
6040-6044	5	Heat Shield Temp. -Sides	2	1.0	10.0	6	60.0	Thermocouples
1739-1740	2	Heat Flux -Forebody	2	1.0	10.0	6	60.0	Calorimeter
1779-1786	8	Heat Flux -Afterbody	2	1.0	10.0	6	60.0	Calorimeter
6060-6064	5	Heat Shield Temp. -Leading Edges	2	1.0	10.0	6	60.0	Thermocouples
6095-6099	5	Heat Shield Temp. -Bottom	2	1.0	10.0	6	60.0	Thermocouples
7110-7113	4	Aero Surface Press. -Fins	1	2.0	50.0	7	350.0	Pressure Transducer

HL-10 RESEARCH TASK

MEASUREMENT LIST - TASK NO. FM-13

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6005-6014	10	H.S. Temp -Nose Cap	2	1.0	10.0	6	60.0	Thermocouples
6020-6034	15	H.S. Temp -Top	2	1.0	10.0	6	60.0	Thermocouples
6040-6054	15	H.S. Temp -Sides	2	1.0	10.0	6	60.0	Thermocouples
6060-6079	20	H.S. Temp. -Leading Edges	2	1.0	10.0	6	60.0	Thermocouples
6095-6114	20	H.S. Temp -Bottom	2	1.0	10.0	6	60.0	Thermocouples
6130-6139	10	H.S. Temp -Elevons	2	1.0	10.0	6	60.0	Thermocouples
6170-6179	10	H.S. Temp -Fins	2	1.0	10.0	6	60.0	Thermocouples
1719-1728	10	Temperature -Gradients	2	1.0	10.0	6	60.0	Thermocouples
6400 6401	2	Surface Recession -Nose Cap	-	1.0 Sec	1.0	4	4.0	Surface Recession Gage
6404-6405	2	Surface Recession -Fore Body	-	1.0 Sec	1.0	4	4.0	Surface Recession Gage
6408-6409	2	Surface Recession -After Body	-	1.0 Sec	1.0	4	4.0	Surface Recession Gage

HL-10 RESEARCH TASK

MEASUREMENT LIST - TASK NO. FM-13

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6412-6413	2	Surface Recession -Fins and Rudder	-	1.0 Sec	1.0	4	4.0	Surface Recession Gage
6416-6417	2	Surface Recession -Elevons	-	1.0 Sec	1.0	4	4.0	Surface Recession Gage
7171-7178	8	Aero Surface Press. -Nose Cap	1	2.0	50.0	7	350.0	Pressure Transducer
7179-7208	30	Aero Surface Press. -Fore Body	1	2.0	50.0	7	350.0	Pressure Transducer
7229-7268	40	Aero Surface Press. -After Body	1	2.0	50.0	7	350.0	Pressure Transducer
7110-7115	6	Aero Surface Press. -Fins	1	2.0	50.0	7	350.0	Pressure Transducer
7120-7127	8	Aero Surface Press. -Elevons	1	2.0	50.0	7	350.0	Pressure Transducer
7156-7163	8	Aero Surface Press. -Rudders	1	2.0	50.0	7	350.0	Pressure Transducer
1739-1746	88	Heat Flux -Fore Body	2	1.0	10.0	6	60.0	Calorimeter
1779-1790	12	Heat Flux -After Body	2	1.0	10.0	6	60.0	Calorimeter
1839-1841	3	Heat Flux -Fins and Rudder	2	1.0	10.0	6	60.0	Calorimeter

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-13

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1859-1860	2	Heat Flux -Elevons	2	1.0	10.0	6	60.0	Calorimeter
7300-7313	14	Noise Level	5	.1	1.0	5	5.0	Microphone
6560-6569	10	Strain H.S. Panels	5	25.0	200.0	5	1000.0	Strain Gage
6420-6429	10	Strain Fore Body Structure	5	25.0	200.0	5	1000.0	Strain Gage
6430-6439	10	Strain After Body Structure	5	25.0	200.0	5	1000.0	Strain Gage
1300-1309	10	Strain Fins and Rudder Structure	5	25.0	200.0	5	1000.0	Strain Gage

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-14

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7171-7178	8	Aero Surface Press. -Nose Cap	1	2.0	50.0	7	350.0	Pressure Transducer
7179-7228	50	Aero Surface Press. -Fore Body	1	2.0	50.0	7	350.0	Pressure Transducer
7229-7298	70	Aero Surface Press. -After Body	1	2.0	50.0	7	350.0	Pressure Transducer
7110-7115	6	Aero Surface Press. -Fins	1	2.0	50.0	7	350.0	Pressure Transducer
7120-7127	8	Aero Surface Press. Elevons	1	2.0	50.0	7	350.0	Pressure Transducer
7156-7163	8	Aero Surface Press. -Rudders	1	2.0	50.0	7	350.0	Pressure Transducer
1320-1339	20	Shear (Friction)	5	25.0	200.0	5	350.0	Strain Gage
1719-1728	10	Temperature Gradient	2	1.0	10.0	6	350.0	Thermocouples
6005-6014	10	H.S. Temp. -Nose Cap	2	1.0	10.0	6	60.0	Thermocouple
6020-6034	15	H.S. Temp. -Top	2	1.0	10.0	6	60.0	Thermocouple
6040-6054	15	H.S. Temp. -Sides	2	1.0	10.0	6	60.0	Thermocouple

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-14

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6060-6079	20	H.S. Temp. -Leading Edge	2	1.0	10.0	6	60.0	Thermocouple
6095-6114	20	H.S. Temp. -Bottom	2	1.0	10.0	6	60.0	Thermocouple
6130-6139	10	H.S. Temp. -Elevons	2	1.0	10.0	6	60.0	Thermocouple
6170-6179	10	H.S. Temp. -Fins	2	1.0	10.0	6	60.0	Thermocouple

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-15

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7171-7174	4	Aero Surface Press. -Nose Cap	1	2.0	50.0	7	350.0	Pressure Transducer
7179-7188	10	Aero Surface Press. -Fore Body	1	2.0	50.0	7	350.0	Pressure Transducer
7229-7258	30	Aero Surface Press. -After Body	1	2.0	50.0	7	350.0	Pressure Transducer
7110-7115	6	Aero Surface Press. -Fins	1	2.0	50.0	7	350.0	Pressure Transducer
6005-6009	5	Heat Shield Temp. -Nose Cap	2	1.0	10.0	6	60.0	Thermocouples
6020-6029	10	Heat Shield Temp. -Top	2	1.0	10.0	6	60.0	Thermocouples
6040-6059	10	Heat Shield Temp. -Sides	2	1.0	10.0	6	60.0	Thermocouples
6170-6174	5	Heat Shield Temp. -Fins	2	1.0	10.0	6	60.0	Thermocouples
1739-1741	3	Heat Flux -Fore Body	2	1.0	10.0	6	60.0	Calorimeter
1779-1785	7	Heat Flux -After Body	2	1.0	10.0	6	60.0	Calorimeter

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-15

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1839-1848	10	Heat Flux -Fins and Rudder	2	1.0	10.0	6	60.0	Calorimeter
6060-6069	10	Heat Shield Temp. -Leading Edges	2	1.0	10.0	6	60.0	Thermocouple
6095-6104	10	Heat Shield Temp. -Bottom	2	1.0	10.0	6	60.0	Thermocouple
6540-6544	5	RF Noise	2	10.0	100.0	6	600.0	Radiometer
6545-6549	5	Electron Density	2	10.0	100.0	6	600.0	Electrostatic Probes
6550-6552	3	Boundry Layer Composition	2	100.0	800.0	6	4800.0	Mass Spectrometer
6553-6555	3	Reflected RF Poser	2	10.0	100.0	6	600.0	Radiometer

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-16

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
0050-0055	6	Transmitter Power	2	10.0	100.0	6	600.0	RF Power
6550-6552	3	Reflected Power	2	10.0	100.0	6	600.0	Radiometer
0056-0058	3	Injectant Flow Rate	2	1.0	10.0	6	60.0	Flow Meter
6060-6064	5	Heat Shield Temp --Leading Edges	2	1.0	10.0	6	60.0	Thermocouple
6095-6099	5	Heat Shield Temp --Bottom	2	1.0	10.0	6	60.0	Thermocouple
7171-7176	6	Aero Surface Press --Nose Cap	1	2.0	50.0	7	350.0	Pressure Transducer
7179-7182	4	Aero Surface Press --Fore Body	1	2.0	50.0	7	350.0	Pressure Transducer
6545-6549	5	Electron Density	2	10.0	100.0	6	600.0	Electrostatic Probes
6550-6552	3	Boundry Layer Composition	2	100.0	800.0	6	4800.0	Mass Spectrometer

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO FM-17

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6020-6024	5	H.S. Temp. -Top	2	1.0	10.0	6	60.0	Thermocouple
6040-6044	5	H.S. Temp. -Sides	2	1.0	10.0	6	60.0	Thermocouple
6060-6074	15	H.S. Temp. -Leading Edges	2	1.0	10.0	6	60.0	Thermocouple
6095-6109	15	H.S. Temp. -Bottom	2	1.0	10.0	6	60.0	Thermocouple
1729-1730	2	Heat Flux -Nose Cap	2	1.0	10.0	6	60.0	Calorimeter
1739-1750	12	Heat Flux- -Fore Body	2	1.0	10.0	6	60.0	Calorimeter
1779-1798	20	Heat Flux -After Body	2	1.0	10.0	6	60.0	Calorimeter
1839-1841	3	Heat Flux -Rudder and Fins	2	1.0	10.0	6	60.0	Calorimeter
1859-1861	3	Heat Flux -Elevons	2	1.0	10.0	6	60.0	Calorimeter
1320-1359	40	Shear (Friction)	5	25.0	200.0	5	1000.0	Strain Gages
7300-7319	20	Boundary Layer Noise Intensity	5	.1	1.0	5	5.0	Microphones

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-18

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1536-1555	20	H.S. Temp.--Ventral Fin	2	1.0	10.0	6	60.0	Thermocouple
6060-6069	10	H.S. Temp.--Leading Edges	2	1.0	10.0	6	60.0	Thermocouple
6095-6104	10	H.S. Temp.--Bottom	2	1.0	10.0	6	60.0	Thermocouple
1300-1319	20	Strain-Fins & Ventral Structure	5	25.0	200.0	5	1000.0	Strain Gage
6224-6225	2	Surface Recession --Ventral Surface	-	1 Sec.	1.0	4	4.0	Surface Recession Gage

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-19

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6005-6014	10	H.S. Temp. -Nose Cap	2	1.0	10.0	6	60.0	Thermocouple
6020-6034	15	H.S. Temp. -Top	2	1.0	10.0	6	60.0	Thermocouple
6040-6054	15	H.S. Temp. -Sides	2	1.0	10.0	6	60.0	Thermocouple
6060-6079	20	H.S. Temp. -Leading Edges	2	1.0	10.0	6	60.0	Thermocouple
6095-6114	20	H.S. Temp. -Bottom	2	1.0	10.0	6	60.0	Thermocouple
6130-6149	20	H.S. Temp. -Elevons	2	1.0	10.0	6	60.0	Thermocouple
6170-6189	20	H.S. Temp. -Fins	2	1.0	10.0	6	60.0	Thermocouple
6235-6254	20	Airframe Temp. -H.S. Panels	2	1.0	10.0	6	60.0	Thermocouple
6285-6304	20	Airframe Temp. -Struct. Skin	2	1.0	10.0	6	60.0	Thermocouple
1719-1728	10	Temperature Gradients	2	1.0	10.0	6	60.0	Thermocouple

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. FM-19

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1729-1738	10	Heat Flux -Nose Cap	2	1.0	10.0	6	60.0	Calorimeter
1739-1778	40	Heat Flux -Fore Body	2	1.0	10.0	6	60.0	Calorimeter
1779-1838	60	Heat Flux -After Body	2	1.0	10.0	6	60.0	Calorimeter
1839-1858	20	Heat Flux -Fins and Rudder	2	1.0	10.0	6	60.0	Calorimeter
1859-1878	20	Heat Flux -Elevons	2	1.0	10.0	6	60.0	Calorimeter
6400-6403	4	Surface Recession -Nose Cap	-	1.0 Sec.	1.0	4	4.0	Surface Recession Gage
6404-6407	4	Surface Recession -Fore Body	-	1.0 Sec.	1.0	4	4.0	Surface Recession Gage
6408-6411	4	Surface Recession -After Body	-	1.0 Sec.	1.0	4	4.0	Surface Recession Gage
6412-6415	4	Surface Recession -Fins and Rudder	-	1.0 Sec.	1.0	4	4.0	Surface Recession Gage
6416-6419	4	Surface Recession -Elevons	-	1.0 Sec.	1.0	4	4.0	Surface Recession Gage

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-1

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5045 5047	3	Position Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5048 5050	3	Velocity Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7100 7102	3	Acceleration	5	25.0	200.0	5	1000.0	Accelerometers
5003 5005	3	Attitude Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5051 5052	2	Angle of Attack Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5053 5055	3	Angle of Attack Measured	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5284 5286	3	Bank Angle Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5056	1	Pilot Alpha Bias Command	----	.1 sec	5.0	14	70.0	Input to Primary IGS Computer
5000 5002	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7034 7043	10	Pilot Control Positions	1	10.0	100.0	7	700.0	Potentiometers
5057 5058	2	Ground Guidance Command	----	1.0 sec	1.0	14	14.0	Command Receiver
5059 5064	6	Ground Navigation Command	----	1.0 sec	1.0	14	14.0	Command Receiver
5065	1	Time Since Deorbit	----	.1 sec	5.0	18	90.0	Timer
5066 5067	2	Horizon Scanner	1	5	50.0	7	350.0	Horizon Scanner

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5045 5047	3	Position Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5048 5050	3	Velocity Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7100 7102	3	Acceleration	5	25.0	200.0	5	1000.0	Accelerometers
5003 5005	3	Attitude Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5051 5052	2	Angle of Attack Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5053 5055	3	Angle of Attack Measured	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5284 5286	3	Bank Angle Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5056	1	Pilot Alpha Bias Command	----	.1 sec	5.0	14	70.0	Input to Primary IGS Computer
5000 5002	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7034 7043	10	Pilot Control Positions	1	10.0	100.0	7	700.0	Potentiometers
5052 5058	2	Ground Guidance Command	----	1 sec	1.0	14	14.0	Command Receiver
5059 5064	6	Ground Navigation Command	----	1 sec	1.0	14	14.0	Command Receiver
5065	1	Time Since Deorbit	----	1 sec	5.0	18	90.0	Timer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-5

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5045 5047	3	Position Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5048 5050	3	Velocity Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7100 7102	3	Acceleration	5	25.0	200.0	5	1000.0	Accelerometers
5003 5005	3	Attitude Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5051 5052	2	Angle of Attack Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5053 5055	3	Angle of Attack Measured	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5284 5286	3	Bank Angle Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5056	1	Pilot Alpha Bias Command	----	.1 sec	5.0	14	70.0	Input to Primary IGS Computer
5000 5002	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7034 7043	10	Pilot Control Positions	1	10.0	100.0	7	700.0	Potentiometers
5057 5058	2	Ground Guidance Command	----	1 sec	1.0	14	14.0	Command Receiver
5059 5064	6	Ground Navigation Command	----	1 sec	1.0	14	14.0	Command Receiver
5065	1	Time Since Deorbit	----	.1 sec	5.0	18	90.0	Timer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5066 5067	2	Horizon Scanner	1	5	50.0	7	350.0	Horizon Scanner
5135	1	Program Time	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5136 5140	5	Programmed Parameters	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5141	1	Integral of Acceleration	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5142	1	Integral of Acceleration Error	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5143 5145	3	Attitude Backup IGS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5146	1	Command Pitch Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5147	1	Command Bank Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5150	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. GN-3

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5153 5154	2	Stellar Reference Angles	1	5.0	50.0	7	350.0	Optical Star Tracker
5155 5156	2	Earth Reference Angles	1	5.0	50.0	7	350.0	Earth Land Mark Tracker
5143 5145	3	Backup Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5157 5159	3	Position Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5160 5162	3	Velocity Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5163 5165	3	Attitude Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5070 5089	20	Experimental Package Diagnostic	----	.1 sec	5.0	14	70.0	Experiment Computer
5105 5119	15	Experimental Package Diagnostic	2	2.0	50.0	6	300.0	Experiment Computer
5003 5005	3	Attitude Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5066 5069	4	Local Vertical Attitude	1	5.0	50.0	7	350.0	Horizon Scanner
5065	1	Time From Deorbit	----	.1 sec	5.0	18	90.0	Timer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-4

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5066 5067	2	Horizon Scanner	1	5	50.0	7	350.0	Horizon Scanner
5135	1	Program Time	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5136 5140	5	Programmed Parameters	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5141	1	Integral of Acceleration	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5142	1	Integral of Acceleration Error	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5143 5145	3	Attitude Backup IGS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5146	1	Command Pitch Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5147	1	Command Bank Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5150 5152	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5157 5159	3	Position Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5160 5162	3	Velocity Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5163 5165	3	Attitude Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-4

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5070 5089	20	Experiment Package Diagnostic	----	.1 sec	5.0	14	70.0	Experiment Computer
5105 5119	15	Experiment Package Diagnostic	2	2.0	50.0	6	300.0	Experiment Computer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-4

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5045 5047	3	Position Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5048 5050	3	Velocity Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7100 7102	3	Acceleration	5	25.0	200.0	5	1000.0	Accelerometers
5003 5005	3	Attitude Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5051 5052	2	Angle of Attack Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5053 5055	3	Angle of Attack Measured	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5284 5286	3	Bank Angle Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5056	1	Pilot Alpha Bias Command	----	.1 sec	5.0	14	70.0	Input to Primary IGS Computer
5000 5002	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7034 7043	10	Pilot Control Positions	1	10.0	100.0	7	700.0	Potentiometers
5057 5058	2	Ground Guidance Command	----	1 sec	1.0	14	14.0	Command Receiver
5059 5064	6	Ground Navigation Command	----	1 sec	1.0	14	14.0	Command Receiver
5065	1	Time Since Deorbit	----	.1 sec	5.0	18	90.0	Timer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-5

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5066 5067	2	Horizon Scanner	1	5	50.0	7	350.0	Horizon Scanner
5135	1	Program Time	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5136 5140	5	Programmed Parameters	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5141	1	Integral of Acceleration	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5142	1	Integral of Acceleration Error	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5143 5145	3	Attitude Backup IGS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5146	1	Command Pitch Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5147	1	Command Bank Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5150 5152	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5157 5159	3	Position Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5160 5162	3	Velocity Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5163 5165	3	Attitude Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-5

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5225	1	Command Alpha	----	.1 sec	5.0	14	70.0	Experiment Computer
5226	1	Measured Alpha	----	.1 sec	5.0	14	70.0	Experiment Computer
5227	1	Command Phi	----	.1 sec	5.0	14	70.0	Experiment Computer
5228 5230	3	Error to FCS	----	.1 sec	5.0	14	70.0	Experiment Computer
5105 5134	30	Experiment Package Diagnostics	2	2.0	50.0	6	300.0	Experiment Computer
5070 5099	30	Experiment Package Diagnostics	----	.1 sec	5.0	14	70.0	Experiment Computer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-6

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5045 5047	3	Position Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5048 5050	3	Velocity Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7100 7102	3	Acceleration	5	25.0	200.0	5	1000.0	Accelerometers
5003 5005	3	Attitude Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5051 5052	2	Angle of Attack Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5053 5055	3	Angle of Attack Measured	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5284 5286	3	Bank Angle Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5056	1	Pilot Alpha Bias Command	----	.1 sec	5.0	14	70.0	Input to Primary IGS Computer
5000 5002	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7034 7043	10	Pilot Control Positions	1	10.0	100.0	7	700.0	Potentiometers
5057 5058	2	Ground Guidance Command	----	1 sec	1.0	14	14.0	Command Receiver
5059 5064	6	Ground Navigation Command	----	1 sec	1.0	14	14.0	Command Receiver

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-6

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5065	1	Time Since Deorbit	----	0.1 sec	5.0	18	90.0	Timer
5066 5067	2	Horizon Scanner	1	5	50.0	7	350.0	Horizon Scanner
5135	1	Program Time	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5136 5140	5	Programmed Parameters	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5141	1	Integral of Acceleration	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5142	1	Integral of Acceleration Error	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5143 5145	3	Attitude Backup IGS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5146	1	Command Pitch Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5147	1	Command Bank Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5150 5152	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5157 5159	3	Position Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5160 5162	3	Velocity Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-6

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5163 5165	3	Attitude Experiment Computer	----	.1 sec	5.0	14	70.0	Experiment Computer
5225	1	Command Alpha	----	.1 sec	5.0	14	70.0	Experiment Computer
5226	1	Measured Alpha	----	.1 sec	5.0	14	70.0	Experiment Computer
5227	1	Command Phi	----	.1 sec	5.0	14	70.0	Experiment Computer
5228 5230	3	Error to FCS	----	.1 sec	5.0	14	70.0	Experiment Computer
5070 5099	30	Experiment Package Diagnostics	----	.1 sec	5.0	14	70.0	Experiment Computer
5105 5734	30	Experiment Package Diagnostics	2	2.0	50.0	6	300.0	Experiment Computer
5231 5239	9	Air Data Signals	2	5.0	50.0	6	300.0	Air Data System
5281 5283	3	Airborne Tracking Data	1	10.0	100.0	7	700.0	Airborne Experimental Sensors
5251	1	Altitude Signals	----	.1 sec	5.0	14	70.0	Airborne Radar Altimeter

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-7

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5045 5047	3	Position Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5048 5050	3	Velocity Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7100 7102	3	Acceleration	5	25.0	200.0	5	1000.0	Accelerometers
5003 5005	3	Attitude Primary IGS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5051 5052	2	Angle of Attack Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5053 5055	3	Angle of Attack Measured	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5284 5286	3	Bank Angle Commanded	----	.1 sec	5.0	14	70.0	Primary IGS Computer
5056	1	Pilot Alpha Bias Command	----	.1 sec	5.0	14	70.0	Input to Primary IGS Computer
5000 5002	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Primary IGS Computer
7034 7043	10	Pilot Control Positions	1	10.0	100.0	7	700.0	Potentiometers
5057 5058	2	Ground Guidance Command	----	1 sec	1.0	14	14.0	Command Receiver
5059 5064	6	Ground Navigation	----	1 sec	1.0	14	14.0	Command Receiver

HL-10 RESEARCH TASK
MEASUREMENT LIST-TASK NO. GN-7

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
5065	1	Time Since Deorbit	----	0.1 sec	5.0	18	90.0	Timer
5066 5067	2	Horizon Scanner	1	5	50.0	7	350.0	Horizon Scanner
5135	1	Program Time	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5136 5140	5	Programmed Parameters	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5141	1	Integral of Acceleration	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5142	1	Integral of Acceleration Error	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5143 5145	3	Attitude Backup IGS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5146	1	Command Pitch Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5147	1	Command Bank Attitude	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5150 5152	3	Error Signals to FCS	----	.1 sec	5.0	14	70.0	Backup Computer Programmer
5231 5250	20	Air Data Signals	2	5.0	50.0	6	300.0	Air Data System

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. HF-1

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
8001-8004	4	Electrocardiogram	5	12.0	100.0	5	500.0	Gemini-Type Electrocardio-graph
8005-8006	2	Blood Press	5	12.0	100.0	5	500.0	Gemini-Type Sphygmomano-meter
8007-8010	4	Respiratory Rate	5	1200	100.0	5	500.0	Gemini-Type Pneumograph
8011-8014	4	Body Temperature	2	1.0	10.0	6	60.0	Thermistor

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. HF-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
8001-8004	4	Electrocardiogram	5	12.0	100.0	5	500.0	Gemini Type Electrocardio-graph
8005-8006	2	Blood Press.	5	12.0	100.0	5	500.0	Gemini-Type Sphygmomanometer
8007-8010	4	Respiratory Rate	5	12.0	100.0	5	500.0	Gemini-Type Pneumograph
8011-8014	4	Body Temperature	2	1.0	10.0	6	60.0	Thermister

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. PP-1

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
7156-7170	15	Aero Surface Press Rudders	1	2.0	50.0	7	350.0	Pressure Transducers
7110-7114	5	Aero Surface Press Fins	1	2.0	50.0	7	350.0	Pressure Transducers
6170-6199	20	H.S. Temp. Fins	2	1.0	10.0	6	60.0	Thermocouples
7100-7105	6	Vehicle Acceleration	5	25.0	200.0	5	1000.0	Accelerometers
1000-1015	16	Nozzle Flow Rate	2	10.0	100.0	6	600.0	Flow Meters
1016-1031	16	Jet Chamber Temperature	2	.5	5.0	6	30.0	Thermocouples
1032-1047	16	Jet Chamber Pressure	2	25.0	200.0	6	1200.0	Pressure Transducers

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. PP-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1032-1047	16	Jet Chamber Pressure	2	25.0	200.0	6	1200.0	Pressure Transducers
1016-1031	16	Jet Chamber Temperature	2	.5	5.0	6	30.0	Thermocouples
7100-7105	6	Vehicle Accelerations	5	25.0	200.0	6	1200.0	Accelerometers

HL-10 RESEARCH TASK
MEASUREMENT LIST - TASK NO. PP-3

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1048	1	Jet Throttle Position	5	1.0	10.0	5	50.0	Potentiometer
1049	1	Fuel Flow	2	10.0	100.0	6	600.0	Flowmeter
1050-1051	2	Fuel Pressure	2	10.0	100.0	6	600.0	Pressure Transducer
1052-1053	2	Thrust	5	10.0	100.0	5	500.0	Load Cells

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-1

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6000-6004	5	H.S. Temp (Antenna)	2	1.0	10.0	6	60.0	Thermo-couples
6005-6019	15	H.S. Temp (Nose Cap)	2	1.0	10.0	6	60.0	Thermo-couples
6020-6039	20	H.S. Temp (Top)	2	1.0	10.0	6	60.0	Thermo-couples
6060-6094	35	H.S. Temp (Leading Edges)	2	1.0	10.0	6	60.0	Thermo-couples
6130-6169	40	H.S. Temp (Elevons)	2	1.0	10.0	6	60.0	Thermo-couples
6170-	30	H.S. Temp (Fins)	2	1.0	10.0	6	60.0	Thermo-couples
1400-1419	20	H.S. Temp (Coves)	2	1.0	10.0	6	60.0	Thermo-couples
1926-1940	15	H.S. Temp (Joints)	2	1.0	10.0	6	60.0	Thermo-couples
6235-6284	50	Air Frame Temp (H.S. Panels)	2	1.0	10.0	6	60.0	Thermo-couples
6285-6324	40	Air Frame Temp (Struct Skin)	2	1.0	10.0	6	60.0	Thermo-couples
6325-6349	25	Air Frame Temp (Elevon Struct)	2	1.0	10.0	6	60.0	Thermo-couples

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-1

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6350-6369	20	Air Frame Temp (Fin Struct)	2	1.0	10.0	6	60.0	Thermo-couples
6370-6399	30	Air Frame Temp (Struct. Frame)	2	1.0	10.0	6	70.0	Thermo-couples
6400-6403	4	Nose Cap Recession	-	1 sec	1.0	4	4.0	Surface Recession Gage
6404-6407	4	Forebody Recession	-	1 sec	1.0	4	4.0	"
6408 6411	4	Aft Body Recession	-	1 sec	1.0	4	4.0	"
6412-6416	4	Fins & Rudder Recession	-	1 sec	1.0	4	4.0	"
6416-6419	4	Elevons Recession	-	1 sec	1.0	4	4.0	Surface Recession Gage
6040-6059	20	H.S. Temp - Sides	2	1.0	10.0	6	60.0	Thermo-couples
6095-6129	35	H.S. Temp - Bottom	2	1.0	10.0	6	60-0	Thermo-couples

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK No. SM-2

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1926-1965	40	H.S. Temp (Joints)	2	1.00	10.0	6	60.0	Thermo-couples
1360-1379	20	Surface Cracking	-	1.0 sec	1.0	1	1.0	Break wire circuit
1556-1595	40	Substrate panel strain	5	25.0	200.0	5	1000.0	Strain gage

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-3

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6445-6454	10	Heat Flux-Special Panels	2	1.00	10.0	6	60.0	Calori-meter
6455-6534	80	Temperature Special Ablative Panels	2	1.00	10.0	6	60.0	Thermo-couples
6535-6539	5	Special Panel Recession	-	1.00 Sec	1.0	4	4.0	Surface Recession Gage
7000-7009	10	Special Panel Pressure	1	2.00	50.0	7	350.0	Pressure Transducer

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-5

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6799-6818	20	Pressure-Insulation Cavity	5	2.0	50.0	5	250.0	Pressure transducer
6819-6858	40	Temp-insulation cavity	2	1.0	10.0	6	60.0	Thermo-couples

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-6

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1779-1788	10	Heat Flux-Aft Body	2	1.0	10.0	6	60.0	Calorimeter
1839-1843	5	Heat Flux-Fins and Rudder	2	1.0	10.0	6	60.0	Calorimeter
1859-1878	5	Heat Flux-Elevons	2	1.0	10.0	6	60.0	Calorimeter
7010-7019	10	Aero Surface Pressure (Coves)	1	2.0	50.0	7	350.0	Pressure Transducer
7020-7029	10	Aero Surface Pressure (Caps)	1	2.0	50.0	7	350.0	Pressure Transducer
7140-7143	4	Hinge Moments (Control Surface)	5	25.0	200.0	5	1000.0	Load Cells
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentiometers
7044-7049	6	Control Surface Dynamic Response	5	200.0	1600.0	5	8000.0	Accelerometers
1400-1499	100	H.S. Temp (Coves)	2	1.0	10.0	6	60.0	Thermocouples

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-7

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6020-6039	20	H.S. Temp Top	2	1.00	10.0	6	60.0	Thermo-couples
6060-6079	20	H.S. Temp Leading Edges	2	1.00	10.0	6	60.0	Themo-couples
6285-6304	20	Airframe Temp. Struct. Skin	2	1.00	10.0	6	60.0	Thermo-couples
6560-6579	20	Ablative H.S. Panels Strain	5	25.00	200.0	5	1000.0	Strain Gages
1360-1399	40	Surface Cracking	-	1.0 sec	1.0	1	1.0	Breakwire Circuit
6040-6059	20	H.S. Temp - Sides	2	1.0	10.0	6	60.0	Thermo-couples
6095-6114	20	H.S. Temp - Bottom	2	1.0	10.0	6	60.0	Thermo-couples

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-9
(Subsequent Flights)

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6005-6006	2	H.S. Temp (Nose Cap)	2	1.0	10.0	6	60.0	Thermo-couples
6020-6021	2	H.S. Temp (Top)	2	1.0	10;0	6	60.0	Thermo-couples
6060-6061	2	H.S. Temp (Leading Edges)	2	1.0	10.0	6	60.0	Thermo-couples
6580-6619	40	Test Panel Temp Radiative	2	1.0	10.0	6	60.0	Thermo-couples
7050-7069	20	Radiative Panel Press	5	2.0	50.0	5	250.0	Pressure Transducer
6040-6041	2	H.S. Temp (Sides)	2	1.0	10.0	6	60.0	Thermo-couples
6095-6096	2	H.S. Temp (Bottom)	2	1.0	10.0	6	60.0	Thermo-couples

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-9
(First Two Flights)

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6005-6014	10	H.S. Temp (Nose Cap)	2	1.0	10.0	6	60.0	Thermo-couples
6020-6029	10	H.S. Temp (Top)	2	1.0	10.0	6	60.0	Thermo-couples
6060-6069	10	H.S. Temp (Leading Edges)	2	1.0	10.0	6	60.0	Thermo-couples
6580-6729	150	Test Panel Temp Radiative	2	1.0	10.0	6	60.0	Thermo-couples
7050-7069	20	Radiative Panel Press	5	2.0	50.0	5	250.0	Pressure Transducer
6040-6049	10	H.S. Temp (Sides)	2	1.0	10.0	6	60.0	Thermo-couples
6095-6104	10	H.S. Temp (Bottom)	2	1.0	10.0	6	60.0	Thermo-couples

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK No. SM-10

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6580-6599	20	Test Panel Temp. Radiative	5	2.0	50.0	5	250.0	Thermo-couples
6730-6753	24	Radiative Test Panels Strain	5	25.0	50.0	5	250.0	Strain Gage
6754-6763	10	Deflection	2	5.0	50.0	6	300.0	Linear Deflection gages

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-11

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6020-6029	10	H. S. Temp Top	2	1.0	10.0	6	60.0	Thermo-couples
6060-6069	10	H. S. Temp (Leading Edges)	2	1.0	10.0	6	60.0	Thermo-couples
6235-6264	30	Airframe Temp (H.S. Panels)	2	1.0	10.0	6	60.0	Thermo-couples
6285-6314	30	Air Frame Temp (Struct Skin)	2	1.0	10.0	6	60.0	Thermo-couples
7229-7269	10	Pressure (afterbody)	1	2.0	50.0	7	350.0	Pressure Transducers
2000-2009	10	Pressure (coolant)	2	1.0	10.0	6	60.0	Pressure Transducers
2010-2013	4	Coolant Flow Rates	5	1.0	10.0	5	60.0	Flow meters
2014-2015	2	Coolant pump power	5	1.0	10.0	5	50.0	Watt meter
6040-6049	10	H. S. Temp (Sides)	2	1.0	10.0	6	60.0	Thermo-couple
6095-6104	10	H. S. Temp (Bottom)	2	1.0	10.0	6	60.0	Thermo-couple

HL-10 RESEARCH TASK
MEASUREMENT LIST TASK NO. SM-12

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1966-1985	20	Bond Separation	-	1.0	1.0	1	1.0	Breadwire Gage
6580-6619	40	Test Panel Temp.	2.0	1.0	10.0	6	60.0	

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-13

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensors
6764-6767	6	H.S. Temp (Special Sensors)	2	1.0	10.0	6	60.0	Thermo-couple
6770-6773	4	Stress Spec. Sensors	5	25.0	200.0	5	1000.0	Strain gages
6774-6778	5	Deflection Special Sensors	2	5.0	50.0	6	300.0	Linear Deflection gages
6779-6786	8	Heat Shield Recession Special Sensors	-	1 sec	1.00	4	4.00	Recession Gages Special
6787-6794	8	Vibration Special Sensors	5	100.0	800.0	5	4000.0	Accelero-meters Special
6795-6798	4	Heat Flux Special Sensors	2	1.0	10.0		60.0	Calori-meters

HL-10 RESEARCH TASKS
MEASUREMENT LISTS - TASK NO. SM-14

Item No.	Qty.	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6005-6009	5	H.S. Temp-Nose Cap	2	1.0	10.0	6	60.0	Thermo-couple
6020-6024	5	H.S. Temp-Top	2	1.0	10.0	6	60.0	Thermo-couple
6060-6069	10	H.S. Temp-Leading Edges	2	1.0	10.0	6	60.0	Thermo-couple
6235-6284	50	Airframe Temp-H.S. Panels	2	1.0	10.0	6	60.0	Thermo-couple
6285-6324	40	Airframe Temp Struct Skin	2	1.0	10.0	6	60.0	Thermo-couple
6325-6349	25	Air Frame Temp Elevon Struct.	2	1.0	10.0	6	60.0	Thermo-couple
6350-6369	20	Air Frame Temp Fin Struct.	2	1.0	10.0	6	60.0	Thermo-couple
6370-6399	30	Airframe Temp Struct Frame	2	1.0	10.0	6	60.0	Thermo-couple
6040-6044	5	H.S. Temp-Sides	2	1.0	10.0	6	60.0	Thermo-couple
6095-6104	10	H.S. Temp-Bottom	2	1.0	10.0	6	60.0	Thermo-couple

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK NO. SM-15

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
6859-6959	100	Temperature Transpiration Cooled Panel	2	1.0	10.0	6	60.0	Thermo-couple
7034-7043	10	Control Positions	1	10.0	100.0	7	700.0	Potentio-meters
6959-6983	25	Heat Flux Special Panels	2	1.0	10.0	6	60.0	Calori-meter
7080-7099	20	Pressure Special Panels	1	2.0	50.0	7	350.0	Pressure transducers
7229-7233	5	Pressure afterbody	1	2.0	50.0	7	350.0	Pressure transducers

HL-10 RESEARCH TASKS
MEASUREMENT LIST - TASK No. SM-16

Item No.	Qty	Measurement type	Accuracy	Frequency response	SPS	No. bits	BPS	Sensor
1500-1523	24	Temp-Test Location	2	1.0	10.0	6	60.0	Thermocouple
1524-1529	6	Heat Flux - Test Location	2	1.0	10.0	6	60.0	Calorimeter
1530-1535	6	Pressure Test Location	1	2.0	50.0	7	350.0	Pressure transducer