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ORBITAL TESTING REQUIREMENTS FOR GUIDANCE AND CONTROL DEVICES

VOLUME I

by F. Hercules and R. Butler

Prepared under Contract No. NASw-1067 *by*
MCDONNELL AIRCRAFT CORPORATION
St. Louis, Mo.
for

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FOREWORD

This report, Volume I, is the first of two volumes reporting work accomplished under Contract NASw-1067 initiated in August 1964.

The program determined what guidance and control technologies would require or could profit from orbital testing, and defines experiments which fulfill these requirements.

This volume summarizes the work performed on this program and describes the procedure by which the experimental selection was accomplished. Volume II of this report contains the descriptions of candidate experiments.

This program was conducted by personnel of the Space and Missile Electronic Systems Department of McDonnell Aircraft Corporation. The chief contributors were: R.P. Bennett, R.E. Butler, F.P. Hercules, E.H. Johnson, P.W. Jones, and P. Seligsohn.

Acknowledgment is made of the assistance of the following during the performance of this study: Prof. R. H. Cannon, Jr. and Dr. D. B. DeBra of Stanford University; Mr. N. S. Johnson and Mr. W. R. Wehrend of the NASA Ames Research Center under whose technical supervision the study was performed.

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1. STUDY SUMMARY

1.1 Introduction - Since the inauguration of the U.S. space program early in 1958 with the successful injection of an Explorer satellite into orbit, advanced guidance techniques have been successfully employed in various programs such as Ranger and Mercury. At the present time, additional sophisticated guidance and control techniques are in various stages of design or flight test in NASA programs such as OGO, NIMBUS, OAO, Surveyor, Gemini and Apollo as well as in several military programs. As space operations become more complex, increasing demands are made on guidance and control equipment and techniques for improved accuracy and reliability, smaller size and weight, lower power consumption, and generally improved operational and performance characteristics. In the past, these demands on guidance and control have been met, in part, by drawing on the broad technological base established by previous aircraft and ballistic missile developments. In addition, limited system testing of advanced devices and concepts on early program flights and piggybacking testing on a few operational flights has been done. However, because of the cost of each space flight test, programs have placed heavy emphasis on the use of ground testing and simulations to verify that the designed equipment will perform as expected in the space environment.

The orbital flight results based on extensive ground tests have not always met expectations, i.e., unanticipated problems and failures have occurred which either compromised or terminated the mission in some cases. These problems and failures have been attributed to design and procedure errors, overlooked phenomena, and limited knowledge of the space environment. Design and procedure errors may occur in any program, hence the need for extensive ground test and initial flight tests to prove the system operation. However, many of the overlooked phenomena simply did not show up in ground tests because of limited testing capabilities. Phenomena such as zero-g, space radiation, multiple space environments, induced environment, earth signature characteristics, and atmospheric attenuation effects are difficult if not impossible to simulate. In addition, only limited knowledge is available on many of these phenomena so that there is less confidence in ground test results.

As a result of previous orbital flight failures and the acknowledged limitations of ground testing, there has developed a natural reluctance to use advanced equipment which has not been evaluated by an orbital flight test when other proven equipment is available. This reluctance may persist even when the advanced equipment demonstrates superior performance in ground tests. If carried to the extreme, this situation could effectively stifle advances in guidance and control technology with a resultant toll on the overall space program. The present technological base has been adequate to meet the demands, primarily because flight tests have been conducted on advanced devices and concepts that were needed for each particular program. However, as the need for improved performance increases, basic design data is required especially on physical phenomena that exist only in the space environment. For example, the designer of external sensors which operate against the earth or celestial bodies requires a detailed definition of the target signature characteristics to design a precision instrument. The precision instrument can then be subjected to both ground and space tests. Similarly, internal sensors and controls such as low-g accelerometers and gravity gradient devices may best be tested in orbit because of the limitations of ground facilities in simulating the desired physical phenomena.

Although orbital testing has been done on a project basis as well as piggyback basis, a special program has not been established for obtaining the desired information and for testing devices that are needed for guidance and control technology advances. The need for orbital tests is not so great that a crash program should be initiated. However, an orderly, coordinated program would offer a number of significant advantages.

Orbital test program advantages can be stated in terms of existing or planned major space programs and the development of advanced guidance and control concepts. Advantages for major programs include the economics of making the experiment test objectives applicable to a large number of projects and of conducting tests on a time scale which will permit re-design without effecting the schedule of large programs. If an orbital test program could reduce the number of demonstration launches or eliminate some (or even one) flight failure in a large program such as Ranger, it would have proven its usefulness. Regarding the development of advanced concepts, an orbital test program would collect fundamental data on target characteristics and background noise which is needed to design better flight sensors and ground simulators. In addition, it would permit the evaluation of advanced equipment and techniques early in the development stage. Such an evaluation would demonstrate the potential usefulness or pinpoint the deficiencies. Development effort could then be concentrated on promising concepts, thus assuring orderly progress in guidance and control technology for future mission requirements.

Using the above background information as a framework, the present study regarding the need for specific experiments was undertaken. The objective of this six month study program was to (a) select the types of spacecraft guidance, navigation and control systems and components requiring test in an actual orbital environment, (b) specify the experiments for such devices, and (c) determine the feasibility of multiple experiments and the constraints imposed on and by feasible satellite payload configurations and support systems. Early in the program it was established that the study (a) should restrict itself to experiments that could be performed prior to the 1970 time period, (b) should concentrate on experiments that are independent of and not concerned with man's performance, (c) should consider experiments that can be designed to provide technical design data where practical, and (d) should endeavor to use the "piggyback" test bed approach in designing the specific experiments.

The over-all study approach comprised the following steps. A master list of candidate experiments was formulated based upon a broad literature search and an extensive survey of the aerospace industry. Promising experiments were selected from the master list based on criteria which encompassed important mission functional requirements, guidance and control state-of-the-art, and ground test capability. In order to place priorities on the promising experiments and to reduce the number of experiments to a manageable level, more rigorous selection and sorting criteria were derived. In essence, the criteria considered urgency of test data in critical areas, adequacy of ground tests, and cost of an adequately designed experiment. Technical descriptions were written for the high priority experiments. These experiments were then evaluated and a commonality analysis performed. This analysis sought to combine individual experiments into logical groups to share common support equipment and carrier vehicles in order to minimize costs and expedite experiment implementation.

The primary results of this study have been (a) delineation of a list of recommended orbital experiments, (b) technical descriptions of the high priority experiments, and (c) derivation and collection of data which may be used to select the desirable approach for conducting the experiments. In addition, a development schedule was provided for each experiment.

1.2 Study Results - Early in the study, the need for an orbital test program of guidance and control devices was supported by literature search, technical studies, and surveys of the aerospace community. Additional strong support for such a program was obtained by evaluating the adequacy of ground testing for verifying correct equipment operation in the space environment. The ground test capability was considered to be a crucial factor in determining the need for specific orbital tests and, for proper evaluation, the following questions were posed:

(1) What are the limitations in ground simulation?

(2) What are the effects of imperfectly simulating the desired phenomena?

Regarding question (1), ground testing was found to be limited or difficult for simulations of zero-g, extremely low torques, fine pointing requirements and the space radiation and multiple environmental effects. In addition, because of limited knowledge and testing complexity, simulators are inadequate in duplicating earth signature characteristics and atmospheric attenuation effects.

The second question can perhaps best be answered qualitatively by recalling a few of the operating problems and failures which have occurred in previous orbital flights and which were attributed, in part, to space environmental conditions. Space radiation effects damaged semiconductor devices in Explorer XIV and XV, TRAAC, TRANSIT IV B and TELESTAR I and caused premature termination of the missions. The Mercury flights experienced various multiple environmental effects such as zero-g and humidity causing an electrical short in an autopilot electronics connector, temperature ranges and fluid behavior in zero-g causing heat transfer problems in power inverters and the astronaut suit coolant loop, etc. In addition, cold cloud effects caused errors in the Mercury horizon sensors. While these various factors did not cause premature termination of manned missions, they did cause operating problems and astronaut discomfort and perhaps may have caused mission termination had the astronaut not been present. Other well known incidents such as the Mariner Canopus tracker problems and the NIMBUS power system bearing failure were attributed, in part, to unanticipated environmental conditions. (Additional details of the above operating problems may be found in Table 2-1, Section 2 of this volume.)

Despite the above cited limitations, it was equally important to recognize the advantages of ground simulation techniques and facilities in selecting experiments. Obviously, experiments which could be performed satisfactorily in these facilities did not satisfy the inherent intent of the over-all study.

Using the ground test capability as a guideline, candidate experiments for orbital test were solicited from the aerospace industry. As a result of the industry surveys, over fifty companies and agencies provided supporting data and candidate experiments for orbital tests. Additional tests were suggested as a result of literature search. The candidate experiment list encompassed uncertain or known problem areas related to guidance, navigation, control and sensor devices or techniques in which knowledge could be gained by acquiring orbital test data. Over 100 orbital experiments (tabulated in Section 3) were delineated as candidates for such tests.

In order to intelligently select the most worthwhile experiments from the master list, it was necessary to recognize important navigation, guidance and control functional requirements for a wide family of space vehicles and missions. In addition, the state-of-the-art of devices and techniques applicable to these functional requirements was assessed. In essence, these functional requirement and technology assessments considered present program and equipment status and extrapolated these based on industry surveys, literature search and engineering judgment. For example, earth local vertical-orbit plane vehicle control was considered a prime requirement for many missions. For medium to synchronous altitude missions, completely passive gravity gradient control techniques are presently being explored. These passive techniques should also be evaluated for low altitude missions because of the potential for long life and decreased weight and power compared to active systems. The passive techniques might then be used as the primary system or as a supplement to extend the operating life of an active primary system. A second example is provided by the requirement for precise earth local vertical sensing which may be needed either for vehicle control or for an autonomous navigation capability. At the present time, the infrared horizon sensor is the most proven concept for sensing vertical; however, the precision is limited by lack of definition of the earth's horizon which limits the sensor accuracy. Orbital tests are needed to better define the earth-space gradient. In addition, since the earth horizon may not be a well behaved physical phenomena, alternate sensing methods such as gravity gradient sensor techniques should be evaluated for the vertical sensing function. Additional guidelines regarding guidance and control technology status relative to mission functional requirements are tabulated in Section 4.

From the considerations regarding ground test capabilities, mission functional requirements, and state-of-the-art, thirty experiments were selected from the master list which were considered to be within the scope of this study and to represent the major needs for orbital test of guidance, navigation and control devices and concepts. The remaining experiments from the candidate list were not evaluated further primarily because, at this time, they were not considered as important as those selected. A number of the experiments not selected might well become prime tests depending on the evaluation and results of an orbital test program. Other experiments were not selected because they were beyond the scope of this study, have had extensive orbital testing, or orbital testing is planned.

The list of thirty experiments (Table 1-1) was subjected to the following selection criteria to establish a primary and secondary classification. (Experiment satisfies criterion if answer is yes.)

a. Are test results for the device or technique required in the near future?

b. Is orbital testing of the device required because of the inadequate simulation of space environment or an unfavorable ground-simulation-to-orbital-test cost ratio?

TABLE 1-1
SELECTED EXPERIMENTS

EXPERIMENT	ORBITAL TEST OBJECTIVE(S)
CATEGORY A	
1. Electrostatic Gyro	Determine drift and suspension system performance.
2. Low-G Accelerometer	Measure bias error or zero offset, scale factor and threshold.
3. Gravity Gradient Sensor	Evaluate performance and obtain design data.
4. Earth Horizon Definition	Determine energy level and stability of horizon in IR and UV spectrum with particular emphasis on 14 – 16 micron IR energy band.
5. Horizon Sensor Accuracy	Evaluate accuracy of a 14 – 16 micron IR sensor.
6. Gas Bearing Performance	Determine performance of self-generating gas bearings.
7. Star Characteristics	Determine spectral energy and noise background of guide stars used for stellar navigation systems.
CATEGORY B	
1. Gravity Gradient Controls – Passive Damping	Evaluate satellite 3-axis control performance and obtain design data using passive orientation and damping technique at low altitude (300 n.m.).
2. Ion Attitude Sensing	Obtain design data and determine accuracy of ion sensing technique for obtaining yaw information.
3. Gyrocompassing	Evaluate performance using an inertial quality gyro platform or strap-down system.
4. High Reliability Horizon Sensor	Evaluate performance of new design concept and low accuracy (1–5°) horizon sensors.
5. Star Recognition	Determine star field device capability for automatically identifying guide stars.
6. Small Impulse Devices	Determine ignition characteristics and average impulse size.
7. Optical Windows and Mirrors	Evaluate surface degradation caused by meteorite damage, radiation deterioration, etc.
8. Bearings and Lubricants	Evaluate high speed bearing life and lubricant feed in zero-g and vacuum.
CATEGORY C	
1. Planet-Moon Vertical Sensor	Evaluate design concept and accuracy of a multi-function device by sensing earth.
2. Gravity Gradient Controls – Active Damping	Evaluate active or semi-active demping of a gravity gradient oriented satellite at low altitude.
3. Automatic Landmark Tracking	Collect target signature data on selected earth features, demonstrate that passive optical tracker can acquire and track unknown landmarks and evaluate tracking accuracy.
4. Microwave Radiometric Local Vertical Sensor	Evaluate feasibility, obtain design data, ultimately determine accuracy.
5. Cryogenic Gyro	Determine drift rate and evaluate system performance.
6. Temperature Rate Flight Control System	Evaluate temperature rate control during re-entry of a high L/D vehicle.
7. Densitometers	Evaluate use of laser, radio isotope, or X-ray densitometers to measure air data parameters in a high L/D re-entry vehicle.
8. Rendezvous Sensors	Determine background noise effects and evaluate advanced sensing techniques.
9. Fluid Systems	Evaluate performance of fluid pumping techniques.
10. V/H Sensing	Evaluate tracking performance.
11. Control Logic	Evaluate control performance and fuel usage rate.
12. Reaction Jets	Demonstrate operation and performance
13. Extravehicular Control	Obtain design dataand evaluate operation of a tethered payload system.
14. Passive Control Techniques	Obtain design data and evaluate performance of sensor magnetic and aerodynamic control techniques.
15. Space Environmental Tests	Verify adequacy of ground tests; demonstrate operation of devices sensitive to zero-G, radiation or multiple environmental effects.

c. Can an orbital experiment be designed to yield useful results?

d. Will experimental results help resolve a critical area?

e. Is the information either limited or not being obtained on another program?

f. Is the cost, complexity, and reliability of the experiment compatible with the need for data?

Application of this selection criteria resulted in the placement of fifteen experiments in the primary group and fifteen experiments in the secondary group. The primary group was further sub-divided into Categories A and B by applying a sorting criteria (See Section 4.3) and the secondary group was designated Category C. The thirty selected experiments are listed in Table 1-1 according to category; however, no priority was given to experiments in each category. The experimentally sought test data falls into five classifications; scientific, design, design verification, proof and life testing. (The type of test data for the A and B experiments is shown in Table 5-1, Section 5.) Either scientific or design data is obtained for all but two of the experiments; Horizon Sensor Accuracy and Gyrocompassing are design verification tests.

Technical descriptions were written for each of the Category A and B experiments defining the desired orbit parameters, stabilization requirements, experiment physical parameters, support equipment functional requirements, data handling requirements, a flight test plan and a development plan. Table 1-2 summarizes the most important of these requirements. (Note the last column which identifies the development "gating" item. The gating item is defined as being the limiting factor in the overall experiment development, i.e., early attention to this item is required to develop the experiment in the estimated time.) Section 5 contains a brief summary description of the selected experiments.

Using the technical descriptions, the individual experiments were evaluated and a commonality analysis performed for the purpose of considering possible approaches

TABLE 1–2
SUMMARY OF CATEGORY A AND B EXPERIMENT REQUIREMENTS

EXPERIMENTS	ORBIT	ORIENTATION	MASTER ATT. REF.	TEST TIME		ELECTRICAL ENERGY (WATT-HRS.)	WEIGHT (LB.)	VOLUME (FT.^{3})	EXPERIMENT DEVELOPMENT	
				DURATION	OPERATE				TIME (MO.)	GATING ITEM
CATEGORY A										
1. Electrostatic Gyro	> 200 n.m.	Inertial	Star Trackers	30 Days	28 Days	6800	20	0.3	16	Suspension Electronics
2. Low-G Accelerometer	> 300 n.m., Circular	Earth – Orbit Plane	None	1 Month	5 Days	300	36	1.2	17	Measurement Apparatus
3. Gravity Gradient Sensor	300–500 n.m., Circular	Earth – Orbit Plane	Star Tracker	3 Days	1.5 Hrs.	135	28	0.7	17	Selection of Low-G Accelerometer
4. Earth Horizon Definition	100–600 n.m., Circular, Polar	Earth – Orbit Plane	Star Tracker/Gyro	2 Weeks	9 Hrs.	8450	284	5.2	14	Fabrication of Master Reference
5. Horizon Sensor Accuracy	100–600 n.m., Circular, Polar	Earth – Orbit Plane	Star Tracker/Gyro	2 Weeks	9 Hrs.	4400	54	0.7	12	Fabrication of Master Reference
6. Gas Bearing Performance	Any	Any	None	4 Days	3.3 Hrs.	30	23	0.3	15	Fabrication of Rotor Assembly
7. Star Characteristics	200–500 n.m.	Inertial	Star Tracker	3–6 Mo.	20 Hrs.	102	32	1.0	14	Fabrication of Gimballed Detector Assembly
CATEGORY B										
1. Gravity Gradient Controls – Passive Damping	300–500 n.m., Circular	Earth – Orbit Plane	Horizon Sensor, Gyrocompass (or Sun Sensor)	1 Day	20 Hrs.	50	35	1.2	6	Vehicle Selection
2. Ion Attitude Sensing	500–3000 n.m., Circular, Polar	Earth – Orbit Plane	Gyrocompass	1 Week	1 Week	3500	24	0.4	7	Gyrocompass Available
3. Gyrocompassing	150–300 n.m., Circular	Earth – Orbit Plane	Sun Sensor or Star Tracker	1 Week	5 Days	3600	21	0.5	10	Fabrication of Master Reference
4. High Reliability Horizon Sensors	200 n.m., Circular Polar	Earth	Horizon Sensor	3–6 Mo.	9 Hrs.	3040	35	0.6	12	Development of Sensor
5. Star Recognition	> 200 n.m., Polar	Pure Inertial and Earth	Star Tracker	3 Days	9 Hrs.	500	35	0.8	12	Star Mapper Development
6. Small Impulse Devices	> 150 n.m.	Any	None	2 Days	50 Min.	14	16	0.4	10	Device and Vehicle Reference
7. Optical Windows and Mirrors	Van Allen Belts	Solar	None	6 Mos.	9 Hrs./Mo.	225/Mo.	13	0.2	9	
8. Bearings & Lubricants	200–600 n.m.	Any	None	6 Mos.	14 Day/Mo.	2900/Mo.	1	0.1	6	

for implementing the experiments. It was found that a number of the experiments did have common requirements and that multiple experiment payloads were feasible. In evaluating multiple experiment payloads, grouping could be based on test duration, orbit, orientation, and master attitude reference requirements. These requirements were used in selecting experiments from Category A and B for the multiple experiment payloads shown in Table 1-3. The stabilization and electrical power requirements must also be considered carefully in evaluating how the experiment can best be implemented. Finally, the mechanical interface, i.e., size, weight, mounting, field-of-view, etc., between experiment and carrier vehicle is extremely important for most of the sensor experiments which require large fields of view or control of the carrier. Additional details on experiment commonality and implementation may be found in Section 6.

Since the selection of the test bed or payload carrier approach is a major consideration in conducting an orbital test program and in detailed experiment design, a preliminary evaluation of possible approaches for conducting experiments was made. The approaches considered were to:

a. Perform single experiments on existing or planned vehicles on either a non-interferenee or a priority basis.

b. Perform multiple experiments on a piggyback integrated payload launched on a vehicle such as Saturn IB or V.

c. Perform multiple experiments on an integrated payload launched by a special vehicle such as a Thor-Delta.

The first two approaches are preferred, based on cost and earlier implementation. Because of the uncertainty regarding available space and support on planned or existing vehicles, the single experiment approach (a) could not be fully evaluated.

TABLE 1-3

MULTIPLE EXPERIMENT GROUPS

GROUP I

Mission Constraints – One week duration; 110 n.m. altitude, near circular, 30° inclination orbit; earth-orbit plane orientation.

Master Attitude Reference – Sun Sensors and Gyrocompass (30 lb., 1.0 ft.^{3}).

EXPERIMENTS (CATEGORY)	LB.	FT.^{3}
Low-G Accelerometer (A)	36	1.2
Gas Bearing Performance (A)	23	0.3
Ion Attitude Sensing (B)	24	0.4
Gyrocompassing (B)	21	0.5
Totals	104	2.4

GROUP II

Mission Constraints – One month duration; 300 n.m. altitude, near circular, near polar orbit; earth-orbit plane and inertial-orbit plane orientation.

Master Attitude References – Gimballed Star Tracker, Sun Sensor, Horizon Sensor (60lb., 2.0 ft.^{3}).

EXPERIMENTS (CATEGORY)	LB.	FT.^{3}
Electrostatic Gyro (A)	20	0.4
Low-G Accelerometer (A)	36	1.2
Horizon Sensor Accuracy (A)	54	0.7
Star Characteristics (A)	32	1.0
Gravity Gradient Controls Passive Damping (B)	35	1.2
Star Recognition (B)	35	0.8
Gyrocompassing (B)	21	0.5
Totals	233	5.8

The last approach (c) may be desirable if a coordinated large scale orbital test program, including other technologies besides guidance and control, is undertaken. With this approach many experiments can be performed simultaneously while sharing many of the basic systems (i.e., master reference, time reference, data handling).

The second approach is a compromise between (a) and (c). It has an advantage over approach (a) in that some of the basic experiment support systems such as the master attitude reference can be shared by several experiments. In addition, the cost per experiment is presumably less than the special vehicle approach assuming the launch vehicle cost is not charged to the experimental program.

Any piggyback approach has the problems associated with carrier vehicle integration and possible interference with the primary mission. Finally, the desired test conditions (orbit parameters, etc.) are less likely to be achieved with a piggyback than with a special vehicle.

1.3 Conclusions - Orbital tests are required to properly evaluate certain guidance, control and navigation devices and techniques. In addition, orbital tests are needed to verify the adequacy of ground test simulation and to obtain design data for improved ground simulators.

Present ground testing facilities are limited or inadequate for simulations of earth signature characteristics, atmospheric attenuation effects, space radiation, multiple environments, and zero-g. Although facility improvements are possible, significant improvements are not foreseen until data is obtained from orbit on earth signature and atmospheric effects. Radiation and multiple environment simulations are expected to remain difficult because of the many variables involved while no solution is anticipated for the problem of simulating long term zero-g.

The specific experiments recommended for orbital test were selected primarily on the basis of technological need. However, test simplicity was a secondary goal and, as a result, component rather than system oriented experiments were defined. Each experiment was described assuming it was to be conducted in a piggyback fashion without manned participation. Even with these assumptions, several methods of conducting each orbital test were usually still practical. A single test method was selected so that typical vehicle constraints could be defined. Where possible, the test method was selected to achieve reasonable accuracy goals while using state-of-the-art measurement instrumentation and keeping the experiment as simple as possible. Many of the experiments are necessarily quite complex since they involve external sensors for viewing the earth or celestial bodies. While this complexity may restrict the number of opportunities to conduct the tests in a piggyback fashion, nevertheless if given priority status, a number of these experiments could be conducted on programs such as OAO, AOSO, Nimbus and Apollo.

For each of the recommended experiments, however, alternate test methods might serve to (1) establish less complex experiments that could more easily be conducted piggyback or (2) obtain additional orbital data either of improved accuracy, on other parameters or over a longer duration. While simple experiments are always desirable from the viewpoint of implementation and cost, care must be exercised to insure that the orbital results are not compromised to an extent where the test is of little value. Certain experiments which involve complex equipment sequencing or star tracking could be simplified by using a man for the sequencing and star identification functions. Additional simplification could be achieved by monitoring fewer parameters or using less accurate measurement instrumentation. However, the latter simplifications usually imply test results of decreased value for the experiments. Thus, as always, there is a compromise between test simplicity and data interpretation.

As a result of evaluating the experiment technical descriptions, conducting commonality analyses, and performing preliminary implementation studies, the following were concluded:

a. Orbital tests can be designed for the fifteen A and B experiments. However, experiments that involve the collection of design data often require complex equipment and operating procedures. For example, Gravity Gradient Sensor, Earth Horizon Definition, and Horizon Sensor Accuracy tests require equipment and procedures similar to that required for an autonomous navigation system test. This complexity resulted despite the goal of maintaining simple test procedures by conducting component-oriented rather than system-oriented experiments.

b. The experiments are sensor rather than controls oriented, i.e., only two of the fifteen experiments involve vehicle controls. This result is primarily attributed to the fact that additional data is needed on target signatures, background noise, and environmental effects in order to design improved sensors.

c. A master attitude measurement reference (star tracker, horizon sensor, etc.) is required for ten of the fifteen experiments. A star tracker is preferred for seven experiments.

d. Vehicle stabilization is required for the majority of the experiments to permit proper sensor operation and to prevent undesirable coupling of vehicle motion into the experimental data. Four experiments desire that rates be 0.05 degrees per second or less with the Low-G Accelerometer having the most stringent requirements. On two experiments stabilization is not critical and nine experiments can be conducted with vehicle control of $\pm$ 0.1 degrees per sec and $\pm$ 1 degree in rate and attitude respectively.

f. Although specific orbit parameters are preferred by the majority of the experiments, all fifteen tests can be conducted in a 300 n.m. altitude, near circular, near polar orbit. However, such an orbit is not optimum for all the experiments. For example, the Earth Horizon Definition test prefers the above eccentricity and inclination but prefers a 150 or 200 n.m. altitude.

g. No major problems are anticipated in meeting the data handling requirements of single or multiple experiments. In the majority of experiments, existing equipment and techniques will meet the orbital and ground requirements. Time correlation between the experiment data and vehicle housekeeping data is required by eleven of the fifteen experiments. All but one experiment requires one percent or better accuracy and ten experiments require orbital data storage.

h. Electrical power requirements represent a major consideration, especially for long duration experiments. For example, a one month test of the Electrostatic Gyro is estimated conservatively to require 6800 watt-hours. However, if multiple experiments are conducted on a single payload, many of the tests can be performed sequentially to minimize the peak power requirements.

i. Man can make a significant contribution toward experiment simplification by performing simple test set-ups and sequencing tasks such as target recognition and acquisition for star trackers and horizon sensors, equipment turn on and off, and re-programming phases of a test. In addition, a manned vehicle offers the possibility of returning the test data and part of the experiment equipment for detailed examination.

j. Category C contains many useful experiments but additional development and study are required to design orbital tests. For example, Automatic Landmark Tracking tests are needed but additional data on target characteristics and work on sensor development are required. Similarly, aerodynamic and solar pressure passive control techniques are considered important but are strongly dependent on vehicle design.

k. Potential problem areas in implementing the A and B experiments include: (1) overall complexity for several Category A experiments including test methods and vehicle stabilization requirements, (2) electrical power requirements for long duration tests, and (3) vehicle mounting for field-of-view or clearance requirements. Possible solutions to reduce complexity involve defining alternate test procedures which may compromise the test results or which may use man.

1. Multiple experiment payloads are feasible when commonality groupings are made according to orbit, orientation, time duration, and master attitude reference requirements. Stabilization and electrical power considerations also influence the groupings. In addition, experiment development time and the test bed approach are important factors. Development time varies between 12 - 17 months and 6 - 12 months for A and B experiments respectively.

1.4 <u>Recommendations</u> - In view of the study conclusions that the Category A and B experiments are desirable for orbital test, it is recommended that the majority of these experiments be carried out. In order to implement these experiments, additional quantitative data is required to define an orbital test program which would advance the state-of-the-art in orbital guidance and control technology. The following steps should be taken in order to rigorously define the best approach to the testing program:

a. A study should be implemented to select the test bed or carrier vehicle approach to be used in an orbital test program assuming the fifteen Category A and B experiments (and possibly others) are to be conducted. The carrier vehicle strongly influences the experiment test method and in many cases, further experiment definition is meaningless until a carrier vehicle is selected. The single and multiple experiment piggyback approaches as well as the special vehicle approach should be evaluated. Strong candidates for the piggyback approaches include Saturn IB and V, Apollo and the Space Stations. Factors which should be considered include cost, schedule, orbit, available space and available support systems. The study should include an evaluation of the trade-offs in using man or manned vehicles for experiment implementation as well as the means of achieving the desired controlled environment. Study recommendations might result in a single approach or combinations of the above approaches being selected. Preliminary data should be provided on carrier/experiment integration, cost trade-offs, and possible single and multiple experiment packages.

b. Using the results of the carrier vehicle study, detailed experiment specifications should be prepared for the majority of Category A and B experiments using the technical descriptions prepared in the present study as a baseline. The specifications should include technical descriptions and test methods based on a detailed analysis of each experiment to be conducted on the selected carrier vehicle. These specifications would be used to obtain cost and delivery data and to recommend specific hardware for the experiments. This data along with carrier vehicle data is then used to conduct cost trade-off studies and to define a comprehensive development plan.

c. Using the selected carrier vehicle approach and a selected experiment configuration, a detailed error analysis for the experiment should be conducted. This analysis should be made both for the orbital approach and for an approach using ground test data, so that a comparison can be made to evaluate the probability of fulfilling mission requirements within the limits of experiment cost.

d. Cost trade-off studies should be conducted considering the carrier vehicles, experiments, and multiple experiment integration. The trade-offs should explore the ability to relax experiment requirements to minimize cost using the state-of-the-art of test hardware and should provide an indication of when experiments should not be conducted because of ground test capability. This study and the previous studies should provide data for defining a comprehensive development plan which includes design, procurement, test, integration, schedules and PERT diagrams.

The following two recommendations are intended to supplement the work performed under this study as well as any succeeding program definition studies and to improve the ground testing capability regarding navigation sensors.

a. The orbital experiments should be updated periodically to accommodate changes in technology requirements, new developments and advanced concepts, and to incorporate the results of orbital tests. This action would minimize duplication in orbital tests by incorporating the results of similar experiments conducted or planned on other programs and would assure orderly progress in space guidance and control state-of-the-art.

b. Ground simulator design studies should be initiated. These studies would incorporate flight test data on earth signature characteristics to design standardized simulators for the earth and atmosphere in selected spectral bands. The intent of these studies and design effort is to provide the capability of designing and testing improved sensors.

2. GROUND TEST CAPABILITY

2.1 General - The inability to adequately simulate the space environment is the primary factor in determining the need for orbital testing. The highest level of confidence is established in a device, technique or concept by evaluating its performance with actual environmental conditions. Several advantages are gained when it is possible to adequately simulate the expected environments on the ground. Ground tests offer flexibility in addition to the generally lower cost. The goal of nearly all testing is to determine device performance characteristics, not only when operating properly but also in failure modes. To this end, ground testing readily permits the experimenter to: (a) change the test method and environment if the results are not as expected; (b) visually examine the device or provide additional instrumentation based upon the results obtained; and (c) change parameters of interest. Ground testing is limited by the lack of knowledge of the environment and target characteristics (such as the earth as seen by a horizon sensor) or the inability to provide adequate simulation (such as near zero-g conditions for extended periods). Orbital testing should be limited to those techniques and devices affected by environmental conditions which cannot be adequately simulated in ground based facilities.

Space environments or environmental conditions which presently cannot be adequately simulated include zero-g, earth and star signature characteristics, earth atmospheric signal attenuation, and combinations of environments.

In assessing the ground test capabilities relative to these environmental conditions, a fundamental question arises regarding the effects of not perfectly simulating the desired conditions. While this question is extremely difficult to answer quantitatively, insight can be gained by recalling some of the problems encountered in previous orbital flights. Table 2-1 summarizes a few of the better

TABLE 2-1
OPERATING PROBLEMS CAUSED BY SPACE ENVIRONMENT

ENVIRONMENTAL CONDITION(S)	PROGRAM	PROBLEM OR FAILURE	EFFECT ON MISSION OPERATIONS
Earth Signature	Mercury	Cold clouds caused error in horizon sensor signal.	Caused error in alignment of attitude gyros and resulted in attitude control fuel being used.
Unknown – Poss-bly combined – pressure temp., dust, etc.	Nimbus	Freeze in solar orientation drive system.	Power system failure caused premature shortening of operating life.
Zero-g induced particles	Mariner	Solar reflection from induced particles caused loss of canopus track.	Required modification of star tracker operational procedure. Attitude control fuel used in re-acquiring.
Radiation	Explorer, TRAAC, TRANSIT, TELESTAR	Semiconductors degraded more rapidly than anticipated.	Solar cell and other semiconductor failures reduced operating life significantly.
Zero-g, humidity	Mercury	Moisture accumulated on electrical connectors, causing short.	Short in connector pins disabled a portion of autopilot electronics.
Zero-g, dust	Mercury	Astronaut suit fan clogged with dust.	Astronaut discomfort.
Contaminants	Mercury	Reaction jets clogged.	Excess fuel usage foreshortened at least one unmanned mission.
Temperature, pressure, Zero-g	Mercury	Heat transfer predictaability caused several inverter and suit problems.	Power inverter failure due to overheating. Unpredicted behavior of fluids in Zero-g and wide temperature dynamic range effected suit cooling loop and caused astronaut discomfort.
Unknown – Possibly combined	Ranger	A variety of problems such as roll gyro inoperative, TV system failure, etc.	The first 6 flights were compromised to some degree e.g., on Ranger II, Agena 2nd burn did not occur probably because roll gyro was inoperative thus depleting attitude control fuel. On flight VI, electrical arcing during launch damaged TV system which had been energized by false signal.
Unknown – possibly combined	OGO	2 experiment booms did not deploy properly on OGO I.	Horizon sensor view of earth obscured by booms. As a result, OGO I could not be earth oriented and it remains spin stabilized at 5 RPM.

known operating problems or failures which were attributed, in part, to environmental conditions. The table also shows qualitatively how the mission operations were effected. (The data shown was abstracted from program summary reports and various trade journals.) Additional problems of a similar nature have occurred because of both limited knowledge and imperfect simulation testing. In cases where knowledge is available but simulation is still difficult, the equipment or system designer may minimize or circumvent the problem as has been the case for most of the problems in Table 2-1. However, where equipment operation is critical to mission success, test in the orbital environment is still required. For example, while the system designer might prefer to use an edge tracking horizon sensor rather than a conical scan unit in order to minimize the cold cloud problem, he would like to verify that the edge tracker will perform as required before compromising an entire mission.

The following paragraphs discuss the actual space environment and the ground simulation capabilities in terms of the vacuum, thermal, radiation, zero-g and combined environments as well as target signature characteristics.

2.2 Vacuum - With increasing altitude from the earth, the pressure encountered by an orbiting vehicle approaches the pressure of the solar system of approximately 10^{-16} mm Hg (torr) due to particle density.

Figure 2-1 is a plot of gas pressure as a function of the distance from the earth's surface. In the figure, nominal pressure ranges and various physical and electrical effects are indicated. A discussion of these regions is contained in the following paragraphs.

a. A vacuum in the pressure range of 10 to 10^{-1} torr is sufficient for testing gross effects; i.e., structural effects and leakage rate.

b. At about 10^{-3} torr aerodynamic damping becomes insignificant. Below this pressure, systems such as directional antennas or optics could be

PRESSURE AS A FUNCTION OF DISTANCE FROM EARTH

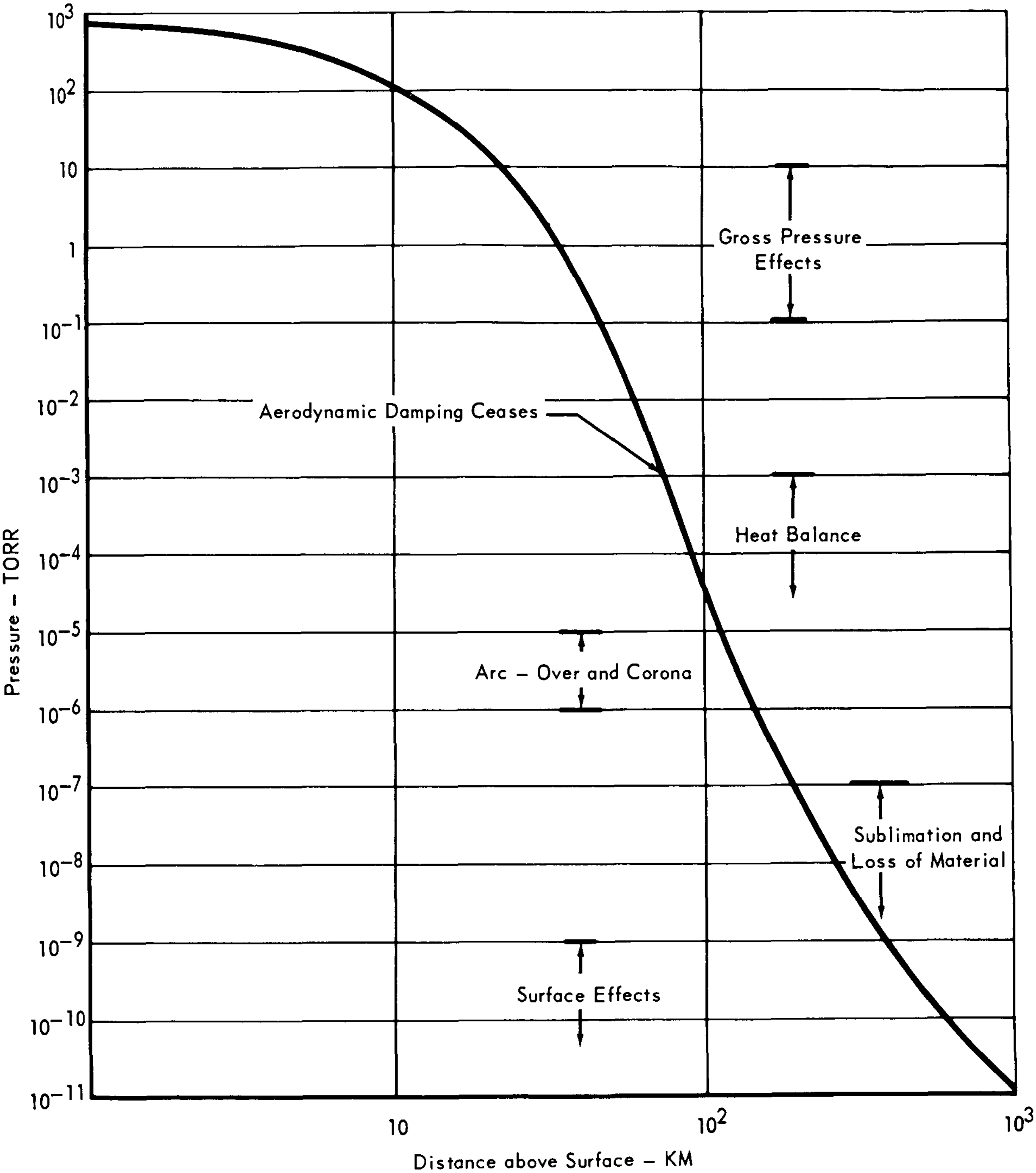

FIGURE 2-1

excited to persistent vibration by impulses from reaction motors or other drives (Reference 1).

c. Between 10^{-3} torr and 10^{-6} torr, convection becomes insignificant. This directly affects the design of electrical equipment where heat loads must be dissipated. Electrical corona discharge and arcing may also occur in this pressure range.

d. Mass loss through evaporation and sublimation begins at a pressure of 10^{-7} torr to 10^{-8} torr. The mass loss may be a cause of many problems such as loss of lubrication, changes in surface properties and degradation of equipment.

e. At pressures of 10^{-11} torr and lower, many combined effects may occur. Matter evaporating or sublimating from warmer areas of the satellite may condense on colder areas. Condensation of organic materials on contacts or metallic materials on insulators may produce electrical malfunctions (Reference 1).

Space acts like a seemingly infinite sink for particles outgassed by a satellite; that is, when gas molecules leave the satellite, they do not in general return to it. In a simulation chamber the gas particles are likely to be reflected from the chamber walls and return to the satellite. This problem of simulation is met by providing a cryogenically cooled surface on which to condense the escaping molecules. The use of liquid helium or gaseous helium below $20^{\circ}K$ as the coolant will cause condensation of most of the gases from the system with the exception of helium.

The pressures needed for most of the ranges previously discussed are readily obtained today. For example, a 30 foot space chamber with no gas load and a cold-plate shroud has an ultimate pressure of 1×10^{-9} torr after twenty-six hours of pumping. With a gas load of 17.1 torr lit/sec. of nitrogen (a gas load 2.5 times the maximum allowable cabin leakage of the Gemini spacecraft) the chamber pressure reaches 1 x 10^{-4} torr after three hours and has an ultimate pressure of 5 x 10^{-5} torr with liquid nitrogen cold shroud coolant. This chamber is pumped by a system of three mechanical pumps and seven 32 inch diffusion pumps. The liquid nitrogen cooled shroud acts as a cryopump.

Pressures on the order of 10^{-11} torr to 10^{-13} torr may be obtained in much smaller chambers using super cooled liquid nitrogen and ion or titanium sublimation pumps. These pressures can be used for testing lubricants exposed to space and for evaluation of cold welding effects.

2.3 <u>Thermal</u> - Except for the sun, the average thermal radiation in space has a power density approximately the same as a black body radiator at a temperature of 3°K. Space has an unlimited apparent heat capacity. At the earth's orbital distance from the sun, the incident power density due to solar radiation is about 1400 watts/m^2 and a spectral distribution equivalent to a 6000°K black body (Reference 2). Ninety-eight percent of the energy in the solar spectrum lies between the wave lengths of 0.3 microns and 4.0 microns with 1 percent of the energy lying beyond each of these limits (Reference 3). The power contributed by solar x-rays will be less than 1 percent of the total solar power delivered at the earth's orbit. Because of the distance from the earth to the sun, the solar radiation that arrives at the earth is essentially in a parallel beam (collimated).

The electromagnetic radiation from a planet (or moon) to a satellite is the resultant of reflected solar radiation or albedo and the planets self-radiation or emission. The earth's albedo represents about 35 percent of the solar energy impinging on the earth. Albedo for other planets and the moon range from 5.6 percent to 93 percent (Reference 4). When a satellite is between the sun and a planet, it receives the full radiant power of the sun on one side and on the other side receives the planetary albedo and emission. When the planet is between the sun and the satellite, the side nearest the planet receives the thermal emission from the planet while its other side radiates to the heat sink of space.

The characteristics of importance to be considered in the design of a solar simulator are discussed below.

a. Collimation - The nominal beam collimation angle should be 2°. The apparent size of the sun simulator should not vary by more than 0.25° with position.

b. Intensity - The collimated beam flux density should be continuously variable from 5 watts/m^2 to 25 watts/m^2.

c. Stability - The radiant flux density of the beam should not vary from the set value by more than $\pm$ 5 percent.

d. Uniformity - The radiant flux density of the collimated beam should not vary spatially in the test volume from the mean set value by more than 10 percent based on a one square inch sensor.

e. Spectrum - The spectral range of the radiant flux in the collimated beam should be from 0.25 microns to 3.0 microns. The spectral deviations are judged by comparison to the Johnson zero air mass curve in 0.1 micron intervals.

There are many types of solar simulators and the type used will depend upon the type of testing desired. For testing a complete satellite, there are no stringent conditions on the quality of the collimated beam but the size of the beam is critical. For testing sensors or solar cells, the beam intensity and spectrum is critical while the size of the beam is not. A compromise between size and quality of the beam must be made to provide effective simulation.

The reflection of solar energy from a planet can usually be simulated to the extent needed for thermal tests by using a reflecting surface of proper physical dimensions and reflectivity in conjunction with a solar simulator. A major problem is the gimbaling system required to produce proper orientations between the planet simulator and the spacecraft under test. The problems of planet thermal simulation are in general procedural and do not involve technical feasibility. Careful consideration must be given to the degree of solar and planet simulation required with respect to the satellite intended mission. Technical ability exists for adequate simulation of most problems that arise. The different problems usually require different degrees and types of solar and planetary simulation.

The simulation of the nearly infinite space heat sink requires the use of chamber cold walls or shrouds similar to those used in high vacuum chambers. The effectiveness of the simulation is a function of the temperature and the cooling capacity of the cold wall. If the cooling capacity of the cold wall shroud is sufficient to carry the heat load of the satellite, the degree of simulation is then a function of the temperature of the cold wall. Use of a temperature of $100^{\circ}K$ rather than the $3^{\circ}K$ background of space introduces an error of only $1^{\circ}K$ in a typical satellite steady state thermal test.

2.4 Radiation - Data from space probes indicate a complex flux of radiation and particles surrounding and streaming toward the earth from the sun and galactic space. Most of the types of radiation and the gross values have been identified including the electrons and protons trapped in the earth's magnetosphere (Van Allen Belts). The penetrating radiation which present satellites must endure is composed largely of cosmic rays and the Van Allen radiation.

Cosmic rays consist of an isotropic flux of high energy particles. The energy of these particles varies from under 10^7 electron volts (ev) to 10^{18} ev. The flux of particles with energy greater than 10^{18} ev is between 5 and 10 particles/cm^2-sec (Reference 2). The particles are about 85 percent protons with the remaining number being mostly alpha particles (2 protons and 2 neutrons) and 1 or 2 percent of heavier nuclei (Reference 5).

The trapped radiation levels of Figure 2-2 are the true counting rates of an Anton 302 Geiger tube carried by Explorer IV and Pioneer III (Reference 6). The

INTENSITY STRUCTURE OF TRAPPED RADIATION AROUND THE EARTH

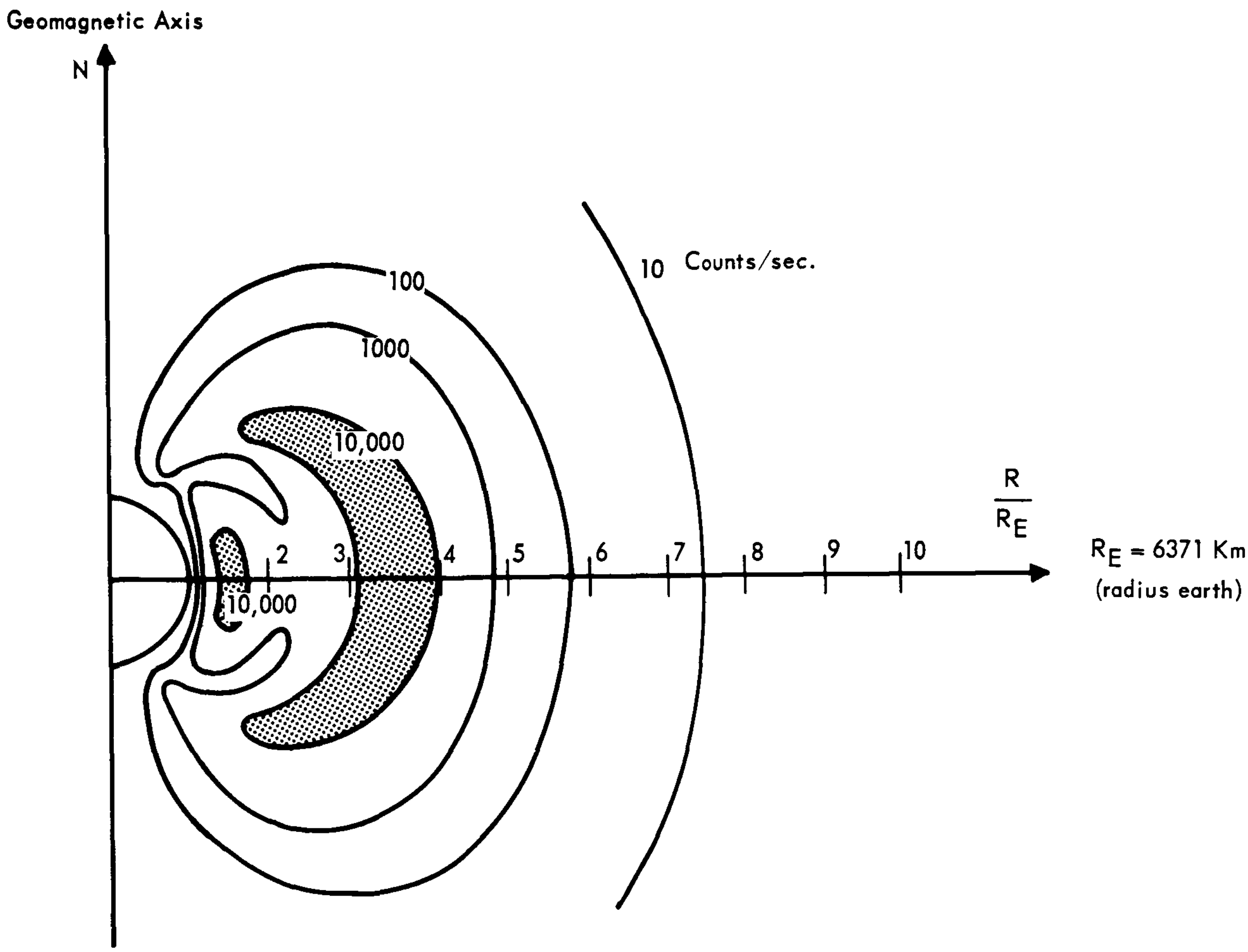

FIGURE 2-2

information on these radiation belts is not complete. Table 2-2 and Table 2-3 present estimates of the radiation that an orbiting vehicle will encounter at altitudes greater than 250 miles.

The energies of the least energetic cosmic rays (around 10^7 ev) and the trapped radiation are producible in the laboratory for testing electrical components and surface effects due to ionization; however, it is not feasible to simulate the radiation portion of the space environment for testing a complete spacecraft.

Satellite systems and components are generally affected by the space radiation through one or more of the following mechanisms:

a. Ionization or excitation of the molecules making up the material.

b. Dislocation of the crystalline structure by ion or electron impact.

c. Contamination of the material by implantation of the bombarding particles.

The effect which is most prevalent in damaging materials is ionization. Typical levels of harmful effects are approximately 10^2 to 10^3 rads for man and 10^{14} to 10^{15} rads for aluminum metal structure.

Transistor and solar cell failures have occurred in satellite systems and components much earlier than predicted, generally as a result of insufficient

TABLE 2-2

ESTIMATED OUTER ZONE RADIATION

PARTICLE TYPE	MINIMUM PARTICLE ENERGY	FLUX (OMNI)
Electron	20 kev	1×10^{11} cm^{-2} sec.$^{-1}$
Electron	200 kev	1×10^{8} cm^{-2} sec.$^{-1}$
Electron	215 mev	10^{6} cm^{-2} sec.$^{-1}$
Proton	60mev	10^{2} cm^{-2} sec.$^{-1}$
Proton	30 mev	0

TABLE 2-3

ESTIMATED INNER ZONE RADIATION

PARTICLE TYPE	MINIMUM PARTICLE ENERGY	FLUX
Electron	20 kev	2×10^9 cm^{-2} $sec.^{-1}$ $ster^{-1}$ (uni)
Electron	600 kev	10^7 cm^{-2} $sec.^{-1}$ $ster^{-1}$ (uni)
Proton	40 mev	2×10^4 cm^{-2} $sec.^{-1}$ (omni)

knowledge of the true environment and insufficient state-of-the-art simulation equipment.

2.5 Zero Gravity - In the absence of drag forces, objects in free fall experience what may be termed as weightlessness, or zero-g. This facet of the space environment poses many problems for the designer. For example, under zero-g conditions the behavior of liquids is dominated by surface tension and viscosity instead of weight. Under zero-g conditions, cooling by convection becomes ineffective.

The simulation of zero-g is very difficult. Some methods of obtaining a short term zero-g environment are:

a. Drop chamber (2 to 5 seconds of free fall).

b. Aircraft in a ballistic trajectory (1 minute).

c. Rocket in a ballistic trajectory (10 minutes).

Limitations on these methods include short test time, complex instrumentation and expense. Some design problems can be partially analyzed through use of suspension and flotation techniques.

2.6 Other Environmental Factors - Additional environmental effects which must be considered include dust particles, meteorites, combined environmental effects and unknown quantities.

A portion of the space mass density is composed of interplanetary dust. This dust tends to be concentrated in small "dust balls" with a density of about 10^{-2} to 1 gm/cm^3 (Reference 2). The average separation of these dust balls is about 300 miles in the earth's gravitational field. Because of the low density, degradation of optics, bearings and other mechanical devices is not expected to be serious except over relatively long operating periods.

It has been calculated that the average collision velocity of meteoroids in the vicinity of the earth is about 35 km/sec which corresponds to kinetic energy of about 10^6 joules/gm. With this velocity, a one gram meteoroid has enough energy to vaporize 50 gms of aluminum. Although the number of meteoroids with a mass sufficiently large to cause damage is very small, it appears probable that a satellite of nominal size will encounter a significant number of meteoroids ranging in mass from less than 10^{-3} gms up to 1 gm in a period of one year (Reference 2). Statistical predictions indicate a 1 mm satellite skin will be punctured sometime between 10 hours and 220 days and that a 1 cm satellite skin would suffer puncture sometime between 1 year and 550 years (Reference 5). Considerably more data on meteoroid density and distribution is required to decrease the range of statistical predictions. The Pegasus meteoroid detection satellite and other planned vehicles should provide significant data to improve the statistical prediction.

The space environment consists of a combination of the individual environments previously discussed as well as possibly unknown conditions. Simultaneous environment simulation in ground tests has been done to only a limited extent. Combined vacuum and temperature, and combined vacuum, temperature and radiation tests have been performed with mixed results. The effect of combined environments is of major concern to the user and the hardware designer. There are many examples of failures of equipment in orbit which are attributed to combined rather than individual environmental conditions. Open or partially open bearing surfaces are susceptible to the entire environment, i.e., outgassing in vacuum, contamination due to dust and particles, degradation of the lubricant due to radiation, and deterioration due to temperature extremes. Electronic equipments are less susceptible to combined orbital conditions than are the mechanical equipments with the possible exception of batteries and fuel cells. Lack of sufficient instrumentation has limited the analysis of the combined space environment effects.

"Induced" environments such as paint particles, dust, lint, radiation, reaction control system gases and loose parts in addition to the natural environment are potential problem sources. Hardware design can compensate for the induced environments if they are anticipated. The Canopus star tracker on a recent Mariner vehicle tracked dust or lint particles which originated from the vehicle. Design allowances could have been incorporated to reduce the effects of the induced environment had it been fully anticipated. A suit fan blower on a Mercury vehicle clogged due to the combination of zero-g and residual dust in the spacecraft cabin. A filter over the fan was subsequently added to reduce the problem. More thorough instrumentation of the satellite hardware would allow improved failure analysis and determination of the unknown effects of combined environments.

2.7 Signature Characteristics - In addition to simulation of environments, ground testing of guidance sensors requires target simulation. The earth or one of the other planets is the target for horizon sensors. The stellar field is to be simulated for star trackers and star mappers. Radar and laser systems require simulation of the target and the surrounding space.

To properly simulate the earth or a planet for horizon sensors requires a detailed knowledge of the spectral characteristics of the plane-space gradient. Information is needed on the distribution and occurrence of anomalies in the gradient.

Likewise, simulation of the star field requires a detailed study of the stellar field as viewed from orbit. Information is needed on the spectral characteristics and magnitudes of the stars. Ground simulation has been unable to predict sensor performance in orbit because of the unknown characteristics. For example, actual horizon sensor performance in orbit has been as much as an order of magnitude poorer than predicted by ground testing. Additional discussion of the signature simulation problem is contained in Experiments on "Earth Horizon Definition" and "Star Characteristics" in Section 2 of Volume II.

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3. CANDIDATE ORBITAL EXPERIMENTS

3.1 Summary - Candidate orbital experiments were determined by considering which guidance, navigation and control devices and techniques would benefit from the results obtainable from orbital tests. In order to make the candidate experiments represent the needs of the aerospace community, a literature search was made, McDonnell project and advanced design groups were surveyed and a survey was made of aerospace contractors and agencies. Figure 3-1 contains a list of companies and agencies who made a significant contribution to this study by suggesting experiments and presenting ideas and data on the needs for orbital tests. As a result of the surveys and literature search, a candidate experiment list was made which contained over one hundred suggested orbital tests. The general ground rules used for including a suggested experiment were:

a. Design or performance data is needed which can best be obtained in orbit;

b. Space environment cannot be adequately simulated by ground equipment; and

c. Proof testing and evaluation is important because of the potential use of the device.

Summaries of candidate experiments in the areas of Vehicle Controls, Attitude Reference Sensors, Navigation Sensors, Advance Concepts, Environment and Life Tests, and Special Vehicles are given in Tables 3-1 through 3-10. For each area, the summaries include the applicable flight testing that has been done or is planned and the suggested additional orbital testing. Section 4 describes the process by which experiments were selected from the candidate experiments.

3.2 Vehicle Controls - Active and passive attitude controls were considered as part of this study. Translation controls are primarily concerned with propulsion devices and, as such, were not thoroughly investigated. Active devices are those which adjust the vehicle momentum vector by expelling mass (e.g. reaction

FIGURE 3-1

CONTRIBUTING COMPANIES AND AGENCIES

Advanced Technology Labs
Aero-Geo-Astro Corp.
AiResearch Manufacturing Co., Div. of Garrett Corp.
Applied Physics Lab, Johns Hopkins University
American Bosch Arma Corp., Arma Div.
Baird-Atomic, Inc.
Ball Brothers Research Corp.
Barnes Engineering Co.
Bell Aerospace Corp.
Bendix Corp., Eclipse-Pioneer Div.
Collins Radio Co.
Farrand Optical Co.
General Electric Co., Defense Electronics Div.
General Electric Co., Missile and Space Div.
General Precision, Inc., Kearfott, Div.
Giannini Controls Corp.
Grumman Aircraft Corp.
Honeywell, Inc.
Hughes Aircraft Co., Space Systems Div.
ITT Federal Labs, Div. of ITT
Kollmorgen Corp.
Kollsman Instrument Corp.
Lear-Siegler, Inc., Instrument Div.
Ling-Temco-Vought, Astronautics Div.
Ling-Temco-Vought, Military Electronics Div.
Litton Systems, Inc., Guidance and Control Systems Div.
Lockheed Aircraft Co.
Marquardt Corporation
McDonnell Aircraft Corporation
MIT, Instrumentation Lab
NASA, Ames Research Center
NASA, Goddard Space Flight Center
NASA, Jet Propulsion Lab
NASA, Langley Research Center
NASA, Lewis Research Center
NASA, Marshall Space Flight Center
NASA, Manned Spacecraft Center
NASA, Office of Advanced Research & Technology
North American Aviation, Autonetics Div.
Northrop Nortronics
Perkin-Elmer Corp., Electro-Optical Div.
Quantic Industries
Raytheon Co., Space and Information Systems Div.
Republic Aviation Corp.
Santa Barbara Research Corp., Div. of Hughes
Sperry Gyroscope Co., Div. of Sperry Rand Corp.
Stanford University, Astronautics Dept.
USAF, Air Force Missile Development Center
USAF, Space Systems Division
USAF, Wright Air Development Center
USN, Bureau of Weapons
Westinghouse Electric Corp., Aerospace Div.

jets) or changing their own momentum vector (e.g. gyroscopic devices). Passive devices function by interaction with the environmental forces which exist at orbital attitudes. These are primarily the magnetic and gravity fields and solar radiation pressure. Summaries of the experiments which involve active devices and passive techniques are given in Tables 3-1 and 3-2. With the exception of small impulse thrusters, active devices can be tested adequately on the ground. Passive devices and small impulse thrusters require space testing because the one-g gravity field encountered in ground tests masks the output force levels from these devices.

Control electronics and extravehicular control techniques are additional areas of interest in the general category of controls. Active control systems require electronics which, in most cases, are tailored to fit the vehicle. These can be divided into fixed-gain and adaptive systems which are further subdivided as follows:

Fixed-gain systems:

a. On-off systems using pulse type torquers (e.g., reaction jets) to control the vehicle to a limit cycle.

b. Purely analog systems using analog torquers (e.g., inertia wheels) to control the vehicle to an absolute reference.

c. Combinations of these.

Adaptive systems:

a. Totally adaptive systems designed to compensate for all variables which may be encountered by the vehicle in any phase of its operation, including the long term orbital phase.

b. Specialized adaptive systems designed to be used during one or more specific phases of operation, such as ascent or re-entry.

TABLE 3-1
ACTIVE CONTROL DEVICES

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED (P)	SUGGESTED ORBITAL TESTS	ADDITIONAL REMARKS
Cold Gas Jets, Monopropellant Jets, Hypergolic Jets	Discoverer, Mercury, Gemini, Nimbus, Explorer, Apollo(P), etc.	• Life • Standby	• Ground tests and orbital tests already conducted or planned are believed adequate • One of these devices used on almost every satellite flown to date
Ion Jet	Project 661A SERT I	• Ion beam neutralization • On-off characteristics • Long-term intermittent operations capability • Response time • Thrust level	• Low disturbance-torque atmosphere required to test low thrust capability • Project 661A provided only one 30 second test run on an ion thruster • Some data can be obtained from ground tests
Plasma Jet	None known	• On-off characteristics • Long-term intermittent operations capability • Response time • Thrust level	• Orbital environment will provide both the stable vacuum and low-disturbance torques required to conduct a satisfactory functional test • Some data can be obtained from ground tests
Detonation Hypergolic Jets, Solid Reaction Jets	None known	• On-off characteristics • Response time • Single-pulse thrust level • Multiple pulse operation • Standby	• Orbital environment will provide low-disturbance torques for testing a low thrust device and zero-g for mechanical proof testing • Most data can be obtained from ground tests
Sublimation Jets, Resistance Jets	None known	• On-off characteristics • Response time • Thrust level • Standby	• Orbital environment will provide low-disturbance torques for testing low-thrust devices • Some data can be obtained from ground tests
Inertia Wheel	Nimbus, OAO(P), OGO	• Standby • Torque resolution • Accuracy	• Ground and orbital tests already conducted or planned are believed adequate to verify device design
Fluid Flywheel	None known	• Wobble damper for spinning vehicle • Pump reliability	• Ground testing will provide all but a final proof test of the device
Inertia Sphere	None known	• Electrostatic suspension at near zero-g	• Potential usefullness of this device does not appear great at this time • Development is progressing very slowly
Control Gyro	Project 661A	• Ball bearing life • Gas bearing stability • Standby • Accuracy	• Ground testing will provide all but a final proof test of the device • Used in project 661A as a momentum dumping device to counteract ion jet thrust
Gyro Stabilizer	Discoverer	• Ball bearing life • Gas bearing stability • Active damping for passive control technique	• Orbital tests already conducted are believed to be adequate

TABLE 3-2

PASSIVE CONTROL TECHNIQUES

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED (P)	SUGGESTED ORBITAL TESTS	ADDITIONAL REMARKS
Gravity Gradient	Discoverer, Transit, ATS (P), TRAAC, 1963 22A	• Evaluate strap-on boom and damper at low altitude	• This would complement ATS program but would evaluate system capability at low altitudes
Magnetic Field	Transit, 1B and 2A, 1963 22A, OAO(P)	• Evaluate 3-axis control using satellite-fixed current coils • Momentum storage and dumping techniques	• At low altitudes large torques are available with relatively low current
Aero-dynamic Force	X-15	• Very low altitude satellites and vehicles re-entering atmosphere could use surfaces and hinge movements for vehicle control	• Vehicle design is important • Autopilot and air data sensors would be needed
Solar Radiation	Mariner	None	• Requires large movable, reflective sail and momentum storage during eclipse

To date, most satellites operating in the orbital mode have employed fixed-gain control systems. The totally adaptive system would optimize fuel consumption and possibly provide more accurate operation. Specialized adaptive systems are being used on launch vehicles during ascent and on the X-15 during all phases of its flight. Paragraph 3.7 provides a brief discussion of sensors for adaptive control of lifting re-entry vehicles.

Extravehicular control techniques may be used to maintain an astronaut's attitude and stability when he is outside the vehicle or to control an external sensor system. Simulation tests can provide some data, but the zero-g orbital environment is required to fully test such devices prior to their employment. Astronaut extravehicular activities are planned for Gemini and Apollo.

TABLE 3-3
OPTICAL REFERENCE SENSORS

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED (P)	SUGGESTED ORBITAL TESTS	ADDITIONAL REMARKS
Sun Sensors, Trackers	OGO, OSO, AOSO(P), Mariner	• Measure accuracy referenced against a precision system	• Ground tests considered satisfactory • Tests have not been conducted in orbit using a precision reference to establish in-flight accuracy
Horizon Sensors	Agena, Discoverer, OGO, Mercury, Saturn, Gemini, Project Scanner(P)	• Evaluate accuracy • Obtain precision measurements of earth IR & UV characteristics • Evaluate long term degradation of unsealed bearings – operating, intermittent operation and long term storage conditions • Evaluate long term degradation of optics, optical materials, detectors when exposed to orbital environment • Evaluate passive finishes used for temperature control • Evaluate bearing life • Evaluate accuracy of IR altimeter application of Horizon Sensor	• Ground testing not sufficient due to lack of knowledge of atmospheric anomaly magnitude and extent • Important space environmental effects include micrometeorites, radiation, UV, and vacuum • Vehicle induced environmental effects include outgasing, jet exhausts, and flaking • Bearing life tests will verify test results obtained in ground vacuum chambers
Star Tracker	Surveyor(P), OAO(P), Mariner	• Evaluate accuracy • Evaluate long term degradation of unsealed bearings – operating, intermittent operation and long term storage conditions • Evaluate bearing life • Evaluate long term degradation of optics, optical materials, detectors, etc., when exposed to orbital environment	• OAO will provide data satisfactory for accuracy evaluation and limited data • Bearing life test will verify results obtained in ground vacuum chambers • Same environmental effects as noted under Horizon Sensors
Star Mappers	Project Scanner	• Determine performance characteristics attitude and rate measurements • Determine characteristics of navigation stars • Evaluate star recognition techniques	• Evaluation of stellar background illumination, star intensity, etc. • Star characteristics obtained on the ground are extrapolated to subtract atmosphere attenuation effects (approximate)
Moon Trackers	Apollo(P), Surveyor (P)	• Evaluate accuracy	• Present knowledge of moon characteristics considered sufficient to design a moon simulator for ground evaluation • Flight would be a proof-test
Planet Tracker	Mariner	• Evaluate accuracy • Measure IR and UV characteristics of the planets from a relatively short range with precision instrumentation	• Present knowledge of Mars and Venus considered satisfactory for long range sensor – more knowledge needed for short range (less than 3 planet radii) evaluation

3.3 Attitude Reference Sensors - Attitude reference sensors provide a measure of the space vehicle attitude variation or rate about a reference set of axes. Optical sensors use the ultraviolet, visual or infrared characteristics of bodies (such as the moon, sun, earth, planets, or stars) to establish a measure of the vehicle attitude relative to the sensed body. Inertial sensors provide a measure of vehicle attitude and rates through use of gyroscopic action. The use of reference body natural forces such as the magnetic field, gravity field or ion distribution provides other techniques for attitude reference.

A wide range of devices and techniques with a broad spectrum of performance parameters have been used in sub-orbital and orbital missions. Performance has not always met expectations due to unanticipated variables or inability to completely evaluate performance of the devices in ground tests prior to flight.

Optical sensors have been used extensively in orbiting vehicles to provide a long term earth or stellar reference. An indication of the sensor types, the applications, and suggested orbital tests is shown in Table 3-3. Short term inertial attitude reference is generally provided by two degree-of-freedom attitude gyros or rate integrating gyros. Life and drift rate are considered as the limiting parameters in the use of gyros in space vehicles. Commonly used inertial sensors, their application and suggested orbital tests are shown in Table 3-4.

Several attitude reference techniques have been proposed which are unique in their application of unusual phenomena. These are summarized in Table 3-5. The advanced concepts discussed in a subsequent section also have attitude reference applications.

3.4 Navigation Sensors - Candidate experiments include both optical and microwave sensors which may be used in orbit determination and rendezvous functions. Suggested experiments and reasons for orbital testing of specific sensor

TABLE 3-4

INERTIAL REFERENCE SENSORS

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED (P)	SUGGESTED ORBITAL TESTS	ADDITIONAL REMARKS
Floated Rate-Integrating Gyro	Agena, Ranger, Gemini, Apollo (P), etc.	• Drift rate stability • General performance and life • Gas bearing stability • Gyrocompass with 3-gyro strapped configuration	• Perform tests with intermittent and continuous operation, also with and without temperature control • All orbital tests presently planned and conducted involve only ball bearing gyros • Gas bearing gyros have flown in ballistic missiles
Rate Gyro	Mercury, Gemini, OAO(P), others	• Low amplitude characteristics • Resolution under near zero-g • Gyrocompass with 3-gyro strapped configuration	• Performance is expected to improve in the low g environment
Two-Degree-of Freedom Gyro	Mercury, Ballistic missiles	• Gyrocompass performance of non-floated, ball bearing gyro • Drift rate performance of case-rotating, gas spin-bearing gyro	• Mercury performed yaw alignment using this gyrocompass configuration but contained no reference for evaluating performance • Ground tests indicate improved drift performance using a case-rotating gyro at reduced wheel spin speed
Gimballed Platform	Ballistic missiles, Gemini, Apollo (P), LEM(P)	• Attitude reference for navigation system test • Gyrocompass performance	• Platforms flown to date are part of an inertial guidance system • Suggested tests would remove accelerometers from inner element • Gyrocompass test could be a 1-, 2-, 3- or 4-gimballed unit

types are included in Tables 3-6 and 3-7 for optical and microwave sensor respectively. Infrared devices are included in the optical sensor summary of Table 3-6. In general, precision navigation sensors require or need orbital testing because of the uncertainties regarding atmospheric and background noise effects.

The optical and inertial attitude reference sensors discussed in Paragraph 3.3 as well as the advanced concepts, Paragraph 3.5, are also useful as navigation

TABLE 3-5
OTHER ATTITUDE REFERENCE SENSORS

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED (P)	SUGGESTED ORBITAL TESTS	ADDITIONAL REMARKS
Ion Sensing	Gemini(P), Aerobee	• Determine accuracy in ion sensing technique for obtaining yaw information	• Aerobee experiments were not designed to sense field direction
Magnetometer	Gemini(P), Pioneer, Explorer, Aerobee, Vanguard, Biosatellite(P)	• Determine feasibility and accuracy of magnetometer attitude control system	• Realistic simulation of magnetic field intensity of orbit not possible on earth's surface • Magnetometer tests to date have been primarily for field measurement and not for attitude control • Sputnik III reportedly employed magnetometer control
V/H Sensor (Velocity/ Height)	Airplanes	• Proof test at orbital altitudes and velocities	• Meaningful data can be obtained using high altitude aircraft

aids. For example, the horizon sensor or star tracker (summarizes in Table 3-3) is directly applicable either as a navigation sensor or as an alignment reference for a gyro stabilized, gimballed platform (see Table 3-4). The gyro stabilized, gimballed platform can serve as a coordinate system for resolving navigation measurements such as the direction of earth geocenter, range and angles to a known earth landmark or to an orbital target, direction of a known star line-of-sight, etc.

Microwave radar is important as a navigation sensor. Current and planned use of altimeters and rendezvous sensors will be expanded to areas such as map matching and active landmark tracking. Features which will improve radars of the future include synthetic aperature, phased arrays, advanced data processing techniques and increased efficiency. Incorporation of these features into a highly

TABLE 3-6
OPTICAL NAVIGATION SENSORS

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED (P)	SUGGESTED ORBITAL TESTS	ADDITIONAL REMARKS
Manual Sextant	Apollo(P), Gemini(P)	• Evaluate the requirement for manual dexterity	• Performance of man as well as instrument needs orbital evaluation
Automatic Sextant	None known	• Measure accuracy of an automatic sextant	• Star tracking principles being evaluated in OAO • Complex systems test evaluating star tracking, landmark tracking or horizon sensors, etc.
Laser Ranging	None known	• Determine accuracy of a laser range and range rate system	• Orbit tests needed to eliminate atmospheric effects of attenuation, scattering and ray bending • Requires target vehicle
Infra-red Target Trackers	None known	• Evaluate accuracy and performance of an IR satellite tracker	• Additional information is needed on IR characteristics of possible satellite targets • Orbit tests needed to eliminate effects of atmospheric attenuation, scattering and ray bending
Optical Trackers	Gemini(P), Apollo(P)	• Evaluate the requirement for manual dexterity	• Performance of man as well as instrument needs orbital evaluation

accurate, all electronic search and tracking radar, lends itself as a versatile orbital guidance and navigation tool.

3.5 Advanced Concepts - Orbital testing may be required in the development of advanced concepts such as those shown in Table 3-8 to:

a. Prove the feasibility of the concept.

b. Aid in solving specific problem areas whose solution is dependent on the orbiting environment.

TABLE 3-7
MICROWAVE NAVIGATION SENSORS

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED (P)	SUGGESTED ORBITAL TESTS	ADDITIONAL REMARKS
Altimeter	Saturn, LEM(P)	• Determine accuracy based on ground track reference	• Previous and planned use limited to low altitude • Orbital radar altimeter problems include power requirements and data processing
Pulse Ranging Radar	Gemini(P)	• Determine performance with non-cooperative targets using advanced concepts	• Testing with non-cooperative targets may require advanced concepts in such areas as antennas, data processing and modulation techniques
Landmark Tracking (Pulse and Doppler)	High altitude aircraft(P)	• Determine accuracy and system performance	• Aircraft testing is adequate for present development; ultimately needs testing in orbit
Doppler Radar	Apollo-LEM(P)	• Same as ranging radar	• Same as ranging radar • Provides accurate velocity • Used for rendezvous
Map Matching (Altitude and Pattern)	Aircraft, Missile(P)	• Obtain data on earth altitude and unique patterns to form master reference for mappers	• Basic development can be carried out in aircraft and missiles

c. Provide proof test results on the operating performance.

3.6 Environment and Life Tests - Typically, the development phase of a new aerospace device is followed by a qualification test and operating life tests in a simulated environment to provide the capability of the device. The major discrepancy in these tests is the impossibility to simulate any one environmental condition precisely or all the environmental conditions simultaneously. Six areas

TABLE 3-8
ADVANCED CONCEPTS

ITEM	POTENTIAL APPLICATION	SUGGESTED ORBITAL EXPERIMENTS	ADDITIONAL REMARKS
Electro-static Gyro	Long term attitude references for control and navigation	• Drift rate performance • Dual suspension voltage tests for launch and orbit • Spin up in orbit	• Drift rate performance of gyro cannot be evaluated on the ground because of gravity induced torques • Spin up in orbit is evaluated and compared to the dual suspension voltage system as an alternate technique
Cryogenic Gyro	All cryogenic inertial guidance and automatic navigation	• Drift rate performance • Remote start-up	• Many of components of an all cryogenic guidance and navigation system are not yet under development • Strapped down cryogenic gyro may be applicable to suggested tests • Further investigation of cooling and pick-off problems required
Low-g Accelerometer	Gravity gradient sensor and low thrust monitor	• Measure bias error or zero offset, scale factor, and threshold • Spacecraft drag and vibration	• Presence of gravity field and seismic noise make ground testing impossible
Gravity Gradient Sensors	Local vertical sensor for control and navigation	• Determine the performance of sensors in defining the direction of the gravity gradient	• Gravity gradient and space disturbances cannot be simulated on the ground • More investigation required to establish complete feasibility
Microwave Horizon Sensor	Local vertical sensor for control and navigation	• Obtain scientific data on the characteristic of the earth's O_2 layer	• High altitude aircraft can obtain data for early development • Ultimately need flight tests at orbital altitude if promising
Passive Landmark Tracking (IR & Microwave)	Navigation aid to obtain precise position	• Obtain scientific data on the characteristics of various types of earth landmarks	• Same as Horizon Sensor (Microwave)

which have special significance in environmental and life testing are summarized in Table 3-9.

Proof testing at the subsystem level is considered worthwhile; however, testing of complete system such as an autonomous navigation system, attitude control system, rendezvous system or solar power orientation system should be preceded by critical component level testing. It is difficult to define useful orbital environmental or life tests on a system whose design is closely related to the mission and vehicle configuration.

3.7 Special Vehicles - Orbital testing of some guidance and control devices requires the use of vehicles having special design characteristics. Conversely, the experiment design is strongly influenced by the test vehicle configuration. Candidate experiments using natural forces for vehicle control generally require special vehicle shapes and control configurations. Gravity gradient oriented vehicles and hypersonic glide re-entry vehicles have these special requirements. Table 3-10 summarizes candidate tests for these two special vehicle areas.

Gravity gradient oriented vehicles require a special inertia configuration in which the axis of least inertia is the earth pointing axis. Since the desired inertia configuration is impractical during boost and staging, a variable geometry vehicle is employed. Inertia changes are accomplished in orbit by extending a boom along the earth pointing axis to obtain the desired inertia configuration. Libration damping is accomplished passively by interactions with auxilliary bodies, spring-mass combinations, and hysteresis losses, or actively by control gyros, reaction jets, and inertia wheels. The variable geometry requirement restricts the families of satellites available for orbital test. However, it has been suggested that a piggyback experiment is practical by affixing a strap-on package containing an extensible boom and damper to the selected vehicle. The

TABLE 3-9
ENVIRONMENT AND LIFE TESTS

ITEM	ORBITAL TESTS CONDUCTED OR PLANNED	SUGGESTED ORBITAL TESTS	REMARKS
Lubrication	OAO(P), OSO, OGO, EGO(P), POGO(P), ARENTS(P), Nimbus, Tiros, Gemini(P), MOL(P), etc.	• Evaluate various lubricants and lubricating techniques for lubricating ability and lifetime	• Extent of lubricant tests on ARENTS program unknown
Bearing Life	OAO(P), OSO, OGO, EGO(P), POGO(P), ARENTS(P), Nimbus, Tiros, Gemini(P), MOL(P), etc.	• Evaluate bearing life under various load and speed conditions with different lubricants • Verify results of ground test programs	• Extensive ground tests in vacuum chambers have indicated good results should be obtainable with proper selection of lubricants • Majority of planned and conducted tests will obtain verification of ground designs by successful operation of equipment
Gas Bearings (hydrodynamic)	None known	• Determine the stability of hydrodynamic gas bearings in an unloaded (near zero-g) condition	• Hydrostatic and hydrodynamic bearings have been used on ballistic vehicles.
Optical Windows, Lens, Mirrors	OAO(P), OGO, Nimbus, Tiros, Apollo(P), MOL(P), etc.	• Evaluate effect of hard vacuum on optical materials • Evaluate effect of radiation on optical materials • Determine sublimation rate of mirrored surfaces • Determine extent and effect of micro-meteoroid impact to optical surfaces • Determine magnitude of particle accumulation and material redepositing on optical surfaces • Determine effect of solar radiation on distortion or warping of large optical surfaces (mirrors, windows). • Determine effect of orbital conditions (temperature, vacuum, near zero-g, etc.) on flatness	• Extensive application • Quantitative effect of environment needed
Radiation Effects	All orbiting vehicles	• Determine the long term effect on electronic assemblies and components of radiation present in the orbital environment	• Quantitative effects require evaluation
Space Storage	MOL(P), Apollo(P), Mariner, Surveyor(P)	• Determine effect of space environment on stored electronic equipment	• Stored denotes a standby condition with power off which will be followed by usage

TABLE 3-10

SPECIAL VEHICLES

ITEM	FLIGHT TESTS CONDUCTED OR PLANNED	SUGGESTED ORBITAL TESTS	REMARKS
Gravity Gradient	Discoverer, Transit, TRAAC, ATS(P)	• Evaluation of a strap-on extensible boom and damper for vehicles	• Initial evaluation may require a special vehicle
Lifting Re.entry	X-15, Asset	• Evaluate densitometers, TRFCS, guidance and adaptive control systems. energy management techniques	• Applicable to vehicles such as NASA M-2 and HL-10

choice of vehicle would be limited by field of view requirements, vehicle geometry and possible interference with other planned experiments.

In the re-entry environment, hypersonic glide vehicles are required for evaluation of air data and temperature rate control devices, such as densitometers and thermocouples. The laser, X-ray and radioisotope densitometers under consideration are designed to penetrate the plasma sheath and measure free stream air density for use in the vehicle flight data computer and autopilot. When properly used, densitometers provide data to determine Mach number, density, altitude, surface heating, angle-of-attack and sideslip angle. Thermocouples imbedded along the vehicle are used as temperature rate sensors in a Temperature Rate Flight Control System (TRFCS). The sensed thermal environment and knowledge of vehicle constraints are used to prevent excessive heating and load factor transients during re-entry energy management.

4. EXPERIMENT SELECTION PROCESS

4.1 General - An extensive list of suggested orbital tests was derived from the survey of the literature, aerospace contractors and government agencies. In order to eliminate unacceptable or questionable tests, a selection criteria had to be formulated. Basically, consideration was given to the most needed mission functions required of navigation, guidance, and control systems.

For the immediate future the following functional requirements were considered to be applicable to a wide family of vehicles:

a. Precise short term and coarse long term local vertical/orbit plane vehicle attitude sensing and control.

b. Precise, short-term stellar attitude determination.

c. Self-contained orbit determination.

d. Coarse solar-oriented control.

e. Rendezvous guidance.

f. Reliable, long-life, low power and weight, coarse attitude control.

g. Nutation damping and spin axis determination of spin stabilized vehicles.

h. Re-entry guidance and energy management for high L/D vehicles.

i. Long life and high reliability.

In reviewing the state-of-the-art devices related to these functions and in considering problems encountered in space vehicles, selection of experiments was based on known problem or desired improvement areas such as the following:

a. Horizon sensors offer the most proven concept for local vertical sensing. Additional data is needed on the earth's signature characteristics for design improvements.

b. Methods, less complex than gyrocompassing, are needed for coarse yaw attitude determination.

c. Improvement is needed in precise local vertical and orbit plane attitude determination systems.

d. Gravity gradient stabilization and other passive techniques should be considered for coarse control of long term missions. Gravity gradient techniques should be extended to include medium to low altitude earth orbits.

e. No precise self-contained orbit determination technique has been developed. Optical sensing and tracking techniques are considered to be limiting this function.

f. Promising advanced concepts such as the electrostatic and cryogenic gyros, low-g accelerometers, gravity gradient sensors, star field devices, and automatic landmark trackers should be evaluated because of their potential value for both attitude and orbit determination functions.

g. Conventional instrument gyro use in space applications will continue; however, techniques for improving life, reducing power consumption and improving drift performance should be fully explored.

h. Reliability and life of high speed rotating equipment is a critical factor for long duration missions. Gas bearings and electrostatic/electromagnetic suspension techniques offer the most promising solutions.

i. The ability to predict space performance of mass expulsion control devices cannot be improved greatly by orbital test. Possible exceptions include ion engines and other very low level thrusters.

j. A wide variety of rendezvous sensing and guidance techniques will be evaluated in the Gemini and Apollo programs. However, advanced techniques and background noise problems may provide areas for future orbital tests.

k. A class of air data and temperature sensors appears promising as supplements to inertial systems for the control, guidance and energy management of high L/D re-entry vehicles.

l. Moving parts exposed to the space environment present a definite design problem.

m. Radiations effects represent a potential environmental problem area. In some cases, unknown radiation effects have caused failures in semiconductor devices. Known environmental effects not considered (such as dust particles in zero-g collecting on exposed bearings) have caused operating problems and failures.

n. An extensive orbital test program would be required to obtain any significant statistical estimate of flight hardware reliability (life testing).

The process of selecting experiments based upon the above requirements went through several iterations resulting in the selection of thirty experiments for further definition (shown in Table 4-1).

4.2 Selection Criteria - The principal guidelines used in selecting the thirty experiments were (a) the device or technique has a high potential usefulness, and (b) the orbital test could be performed at modest cost and complexity. These guidelines were combined with the considerations discussed in Paragraph 3.1 (which were used in compiling the suggested experiment lists) to form the nucleus of a selection criteria. The selection criteria were then used as an aid in the delineation of the thirty experiments into two groups based on conformance to the criteria. The following criteria were applied to each device or technique to establish a priority of experiments.

a. Test results for this device or technique are required in the near future. If this device or technique is to be developed for use on space vehicles

TABLE 4-1
SELECTED EXPERIMENTS

EXPERIMENT	ORBITAL TEST OBJECTIVE(S)
1. Electrostatic Gyro	Determine drift and suspension system performance.
2. Low-G Accelerometer	Measure bias error or zero offset, scale factor and threshold.
3. Gravity Gradient Sensor	Evaluate performance and obtain design data.
4. Earth Horizon Definition	Determine energy level and stability of horizon in IR and UV spectrum with particular emphasis on 14 – 16 micron IR energy band.
5. Horizon Sensor Accuracy	Evaluate accuracy of a 14 – 16 micron IR sensor.
6. Gas Bearing Performance	Determine performance of self-generating gas bearings.
7. Star Characteristics	Determine spectral energy and noise background of guide stars used for stellar navigation systems.
8. Gravity Gradient Controls-Passive Damping	Evaluate satellite 3-axis control performance and obtain design using passive orientation and damping techniques at low altitude (300 n.m.)
9. Ion Attitude Sensing	Obtain design data and determine accuracy ot ion sensing technique tor obtaining yaw information.
10. Gyrocompassing	Evaluate performance using an inertial quality gyro platform or strapdown system.
11. High Reliability Horizon Sensor	Evaluate performance of new design concept and low accuracy (1–5°) horizon sensor.
12. Star Recognition	Determine star field device capability for automatically identifying guide stars.
13. Small Impulse Devices	Determine ignition characteristics and average impulse size.
14. Optical Windows and Mirrors	Evaluate surface degradation caused by meteorite damage, radiation deterioration, etc.
15. Bearings and Lubricants	Evaluate high speed bearing life and lubricant feed in zero-g and vacuum.
16. Planet-Moon Vertical Sensor	Evaluate design concept and accuracy of a multi-function device by sensing earth.
17. Gravity Gradient Controls-Active Damping	Evaluate active or semi-active damping of a gravity gradient oriented satellite at low altitude.
18. Automatic Landmark Tracking	Collect target signature data on selected earth features, demonstrate that passive optical tracker can acquire and track unknown landmarks and evaluate tracking accuracy.
19. Microwave Radiometric Local Vertical Sensor	Evaluate feasibility, obtain design data, ultimately determine accuracy.
20. Cryogenic Gyro	Determine drift rate and evaluate system performance.
21. Temperature Rate Flight Control System	Evaluate temperature rate control during re-entry of a high L/D vehicle.
22. Densitometers	Evaluate use of laser, radio isotope, or X-ray densitometers to measure air data parameters in a high L/D re-entry vehicle.
23. Rendezvous Sensors	Determine background noise effects and evaluate advanced sensing techniques.
24. Fluid Systems	Evaluate performance of fluid pumping techniques.
25. V/H Sensing	Evaluate tracking performance.
26. Control Logic	Evaluate control performance and fuel usage rate.
27. Reaction Jets	Demonstrate operation and performance.
28. Extravehicular Controls	Obtain design data and evaluate operation of a tethered payload system.
29. Passive Control Techniques	Obtain design data and evaluate performance of solar and aerodynamic control techniques.
30. Space Environmental Tests	Verify adequacy of ground tests; demonstrate operation of devices sensitive to zero-g, radiation or multiple environmental effects.

in the near future, immediate testing under actual or accurately simulated space environment is required.

b. Orbital testing of this device is required because of inadequate ground simulation of the space environment or an unfavorable ground simulation-to-orbital test cost ratio. Ground simulation may not adequately duplicate real space for a sufficient period of time. In certain situations, such as the simulation of combinations of several environmental effects, ground testing may be economically impractical.

c. An orbital experiment can be designed which will yield useful results. The performance of an experiment with the candidate device or technique would not require the use of procedures, concepts, devices, and/or techniques which are beyond the state-of-the-art.

d. Experimental data will help resolve a critical area. A critical area of uncertainty exists in the development or utilization of the device or technique. Therefore experimental data is required to advance the state-of-the-art.

e. The information is either limited or not being obtained on another program. The information required to develop and/or utilize the device or technique is not being obtained with sufficient accuracy or in enough detail to resolve the critical problems. In certain instances modification of planned experiments or deviation in the flight plan of others would allow the needed data to be obtained. However, in lieu of such modifications and/or deviations, additional experiments must be performed.

f. The cost, complexity, and reliability of the experiment are compatible with the need for data. The experiment is required to obtain data to develop, utilize or advance the state-of-the-art of a device or technique. Therefore the increased cost and complexity of an orbital test

TABLE 4–2

APPLICATION OF SELECTION CRITERIA TO OBTAIN PRIMARY EXPERIMENTS

EXPERIMENTS	(A) RESULTS REQUIRED	(B) GRD. TESTS INADEQUATE	(C) EXP. CAN BE DESIGNED	(D) CRITICAL AREA RESOL.	(E) INFO. NOT OBTAINED	(F) COST COMPATIBLE
1. Electrostatic Gyro	X	X	X	X	X	X
2. Low-G Accelerometer	X	X	X	X	X	X
3. Gravity Gradient Sensor	X	X	X	X	X	X
4. Earth Horizon Definition	X	X	X	X	X	X
5. Horizon Scanner Accuracy	X	X	X	X	X	X
6. Gas Bearing Stability	X	X	X	X	X	X
7. Star Characteristics	X	X	X	X	X	X
8. Gravity Gradient Sate!lite – Passive Damping	X	X	X	X	*	X
9. Ion Attitude Sensing	X	X	X	X	X	X
10. Gyrocompassing	X	X	X	*	*	X
11. High Reliability Horizon Sensor	X	X	X	X	X	X
12. Star Recognition	X	X	*	X	X	X
13. Small Impulse Devices	X	*	X	X	*	X
14. Optical Windows and Mirrors	X	*	X	X	*	X
15. Bearings and Lubricants	X	*	*	X	X	X
16. Planet – Moon Vertical Sensor	*	*	*	X	*	*
17. Gravity Gradient Satellite – Active Damping	*	X	X	X	X	*
18. Automatic Landmark Tracking	*	*	*	X	X	*
19. Microwave Radiometric Local Vertical Sensor	*	*	X	X	X	*
20. Cryogenic Gyro	*	X	*	X	X	*
21. Temperature Rate Flight Control System	*	X	*	X	X	*
22. Densitometers	*	X	*	X	X	*
23. Rendezvous Sensors	X	X	*	X	*	X
24. Fluid Systems	*	*	X	X	X	*
25. V/H Sensing	*	*	*	X	X	*
26. Control Logic	X	*	*	X	*	*
27. Reaction Jets	X	*	X	X	*	*
28. Extravehicular Control	*	X	*	X	*	*
29. Passive Control Techniques	*	X	X	X	*	*
30. Space Environment Tests	*	*	X	X	*	*

X – Acceptable   * – Questionable

is justified. The reliability will be sufficiently high so that the experiment will yield useful results.

4.3 Application of Selection Criteria - Each of the thirty experiments was subjected to the selection criteria as shown in Table 4-2 and the experiments were then categorized into primary and secondary groups depending on how well they satisfied the criteria. The primary experiment group, numbers 1 through 15, was further subdivided by applying the following sorting criteria:

a. Orbital testing of this device or technique is required because of inadequate simulation of the space environment.

b. The required information is not being obtained on another program.

c. Confidence in the orbital performance data is increased by a factor greater than four over previous test data (either ground or orbit tests).

d. The tests are "technology" rather than "Project" oriented.

e. The device or concept will be sufficiently developed for orbital flight tests in the 1966-1970 time span.

If the reply to all of the statements was positive for an experiment, the experiment was given top priority and placed in Category A. In general, the Category A experiments have a high potential for future applications; ground laboratory simulation is inadequate, and similar tests are not being performed on other programs.

Experiments which did not satisfy all of the second criteria were placed in Category B. No priority of experiments was given within a Category.

Category C, the secondary experiments from Table 4-1, was reserved for those experiments which were considered worthwhile for further study but which were not to be fully explored on this program. The majority of these experiments require more ground development testing to further validate the need for orbital tests while some are strongly dependent on total vehicle design.

The final result was the selection of seven top priority experiments in Category A, eight priority experiments in Category B, and fifteen secondary experiments in Category C. The breakdown from Table 4-1 is:

Category A: Experiments 1 through 7

Category B: Experiments 8 through 15

Category C: Experiments 16 through 30.

5. SELECTED EXPERIMENTS

5.1 General. - This section presents a summary of the orbital testing considered for each of the thirty experiments selected and categorized in Section 4. In general, more than one orbital test is required to fully evaluate a particular device or concept, although the experiment title may seem to imply that a single orbital test will suffice. Such diverse applications as bearings and lubricants or passive controls may require five or more orbital tests. Volume II contains a detailed technical description of each Category A and B Experiment and a discussion of suggested tests for the Category C Experiments. Design data and design verification data are obtained on the majority of the Category A and B Experiments as shown by Table 5-1. No attempt has been made to place priority on experiments in a given category.

5.2 Category A Experiments. - The following paragraphs summarize the Category A Experiments. A detailed technical description for each experiment is contained in Section 2 of Volume II.

Electrostatic Gyro - The suggested Electrostatic Gyro orbital tests are intended to demonstrate the projected high accuracy in a space environment and to investigate the operational problems associated with using the gyro in a space vehicle. Drift rates considerably less than 0.01 degrees per hour are expected. This device has high potential as a long term attitude reference for both control and as part of a navigation system. Drift performance cannot be evaluated by ground tests because of the gravity induced torques. A body mounted two degree-of-freedom electrostatic gyro is used in the proposed experiment. One week drift tests are conducted at medium and low levels of suspension. In addition, remote start and de-spin characteristics are determined. A more complete test program would include a second flight using two gyros for 3 axis information in a strapdown

TABLE 5-1
TYPE OF EXPERIMENTAL TEST DATA

EXPERIMENTS	SCIENTIFIC	DESIGN	DESIGN VERIFICATION	PROOF TESTING	LIFE TESTING
CATEGORY A					
1. Electrostatic Gyro		X	X		
2. Low-G Accelerometer		X	X		
3. Gravity Gradient Sensors		X	X		
4. Earth Horizon Definition	X	X			
5. Horizon Sensor Accuracy			X		
6. Gas Bearing Performance		X	X		
7. Star Characteristics	X	X			
CATEGORY B					
1. Gravity Gradient Controls-Passive Damping		X	X		
2. Ion Attitude Sensing	X	X	X		
3. Gyrocompassing			X	X	
4. High Reliability Horizon Sensor		X	X		
5. Star Recognition		X	X		
6. Small Impulse Devices		X	X	X	
7. Optical Windows and Mirrors	X	X			X
8. Bearings and Lubricants		X	X	X	X

configuration and a third flight using two gyros and a star tracker on a gimballed platform. The latter two experiments would use a suspension system found to be near optimum from the first test.

Low-G Accelerometer - The major objective of this test is to measure the important performance parameters of a low-g accelerometer. In addition, vehicle drag and vibration may be obtained from this test. Accelerometer parameters to be measured include bias error or zero offset, scale factor and threshold. The accelerometer considered for this test has a capability of measuring accelerations from 10^{-4} g to 10^{-10} g. This device has potential use in gravity gradient sensors, low-thrust control systems, station keeping and navigation for long term interplanetary missions. It cannot be ground tested because of the presence of the gravity field and seismic disturbances. The accelerometer used in the experiment employs an electrostatically suspended proof mass. However, the measurement techniques are applicable to most accelerometers in the 10^{-4} to 10^{-10} g range. Vehicle produced acceleration forces are the largest error producing sources in the experiment. Data analysis will provide information on these effects, and also on the feasibility of employing low-g accelerometer concepts, means of eliminating noise (filtering), evaluation of damping and isolation characteristics of different materials.

Gravity Gradient Sensor - Gravity gradient sensor orbital tests are intended to (1) demonstrate the accuracy of the device in a space environment, (2) measure error producing sources to facilitate ground testing, and (3) obtain design data. The gravity gradient sensor is applicable for use as a precision local vertical reference for navigation and attitude control. Space environment disturbance sources and relative field strength cannot be simulated on ground. No gravity gradient sensors have been flown. Potential accuracy is great if the instrument can be designed to sense the small forces and if vehicle effects can be eliminated. The gravity gradient sensor for the experiment consists of a low-g accelerometer mounted on a rotating wheel. The wheel is rotated in the orbit plane and the accelerometer senses the tangential component of acceleration on the rotating wheel. The output waveform is a sine wave whose phase determines the direction of local vertical in the orbit plane. The method of using a rotating wheel eliminates the effects of most error producing sources. Follow-on testing could expand the system to a two axis sensor, and could attempt to improve system accuracy through knowledge acquired in the first test. Various types of accelerometers could also be evaluated in succeeding tests.

Earth Horizon Definition - The objective of this experiment is to measure the earth-space gradient characteristics with precision instrumentation. The information derived is to be utilized in establishing the ultimate accuracy of an optimized horizon sensor. Basic scientific data is needed to intelligently design a horizon scanner. If the stability of the earth's IR gradient is found to be insufficiently stable to design an accurate horizon scanner, development efforts on this approach should be discontinued. TIROS, NIMBUS, Project Scanner and other programs are obtaining data, but the data is either of insufficient duration or accuracy to supply the needs. Statistical data is required on the earth IR gradient slope, magnitude and variations in order to evolve an improved design and to establish the ultimate accuracy of a horizon sensor. Several precision horizon sensor units are being or have been designed and developed. Improved units and performances are needed. Precision data on the IR characteristics is needed in order to accomplish the improvement. Although a wide variety of sensor types exist, essentially all of the horizon sensors use the IR gradient. The proposed experiment employs radiometers to measure the earth's radiation in the 14 to 16 micron, the 20-35 micron and the 2000 to 4500 angstrom bands. Data to determine long term stability of the gradient is provided. A precision attitude reference is required for the experiment. Additional flights may be required to measure the gradient in more selected bands, and to obtain additional data for design of earth IR simulators.

Horizon Sensor Accuracy - The objective of this experiment is to measure the inflight accuracy of a horizon sensor system using a star tracker system as reference. The star tracker system will yield data from which a precision measure of the spacecraft attitude can be obtained. This data, when compared to the horizon sensor outputs, will provide a precision evaluation of the horizon sensor performance in establishing local vertical. Laboratory testing does not provide sufficient information on performance of horizon sensors in the presence of IR gradient anomalies. There is insufficient knowledge on the types and extent of the IR anomalies to design ground test equipment which would provide the needed evaluation. Precision horizon sensors have been flown on several programs and performance has not met the expectations. The test results are qualitative rather than quantitative due to lack of a precision reference against which the unit can be checked. A large number of programs require precision horizon sensors - MOL, MORL, OGO, Gemini and others. Development of improved units cannot proceed much further without definite precision measurements on existing units and without obtaining more information on the earth IR gradient characteristics. Although several different types of horizon sensing techniques exist, proper instrumentation of the recommended system for this experiment will provide information useful to the design of other systems. Experiments should be repeated until the best energy bands are found. Then the optimized system should be flown to measure optimum system accuracy and compared to the accuracy predicted by test on an earth IR simulator.

Gas Bearing Performance - The objective of this experiment is to measure the stability characteristics of a gas-bearing wheel in a zero-g environment.

Bearing reliability is a major problem in many space programs. Development of the air-bearing is considered a prime solution for many applications. The stability of an unloaded (zero-g) bearing in all axes is questionable. A relatively simple orbital test can be designed which will resolve this unknown. Three different air bearing configurations, demonstrated to be stable in lab tests, are evaluated in the initial orbital test. Problem areas will dictate future tests or if one design should be concentrated upon. Success of this test will be of direct benefit to gyro designs and other high speed bearing applications.

Star Characteristics - The objective of this experiment is to measure the broad band spectral characteristics of a few of the major navigation stars. The measurements are in the 3000 Angstrom to 7000 Angstrom spectral band used principally by automatic star trackers and star mappers. The data obtained is to be modified to yield Color Corrected Magnitudes (CCM) of the stars for use with various types of photomultiplier and vidicon detectors as well as for correlation with presently available ground measurements. Tests from Astronomical Observatories and lab facilities have provided data on typical guide stars to an accuracy of $\pm$ 0.2 star magnitudes in the visible spectral bands. Data accuracy in the UV spectral band is approximately $\pm$ 1.0 star magnitude or more. Data is extrapolated to take into account atmospheric attenuation. OAO will obtain information outside the atmosphere but not in the desired spectral bands and not necessarily of the desired stars. A large number of measuring techniques could be used. One specific method as applied to the engineering development of star trackers/star mappers is described in the experiment description. The experiment provides data on the intensity of guide stars in the visible light spectrum used by present day star trackers. An important goal of the experiment is to determine the predictability of atmospheric attenuation and its effect on background noise limit for ground test. Only one flight is planned.

5.3 Category B Experiments - The following paragraphs summarize the Class B experiments. Detailed descriptions of these experiments are contained in Section 3 of Volume II.

Gravity Gradient Controls - Passive Damping - The objective of this experiment is to determine the accuracy with which a satellite in a low altitude earth orbit may be aligned in three axes by an external torque due to the gradient of the gravitational field using only passive techniques. Vehicle configuration constraints will probably require that an extensible boom and damper be affixed to the vehicle as a strap-on package. Since information on passive gravity gradient stabilization is being obtained on other programs (ATS, Discoverer, Transit, Comsat, etc.), and since there are a variety of approaches, some of which have already been demonstrated, a comprehensive study is needed to determine the optimum configuration. The Ames approach is considered because it saves weight, is less complex, and should result in higher accuracy and faster damping than other methods. A series of tests exploring the effects of orbital eccentricity, boom and damper configuration variations, and different vehicle shapes should be run to determine the ultimate capability of the passive approach. Potential applications for long life, earth orbiting vehicles are great.

Ion Attitude Sensing - The primary purpose of the experiment is to demonstrate the feasibility of determining vehicle yaw attitude for near earth orbital vehicles by ion sensing techniques. It is further desired to obtain a measure of the yaw attitude sensing accuracy. Finally, it is desired to instrument the experiment to obtain a partial evaluation of the effects of vehicle-ionosphere interaction on ion attitude sensing. Ion sensing offers an attractive method for obtaining coarse pitch and yaw attitude information. Flights on Aerobee rockets have verified that enough ions are present in the near earth region to provide sensing information. An ion attitude experiment is planned on one of the Gemini flights. Additional testing is needed to determine feasibility and to provide data for sensor design. Initial testing will evaluate the single axis device with a gyrocompass as the master measurement reference. Further tests could include effects of gas expulsion on system accuracy and the test expanded to include a two-axis pitch and yaw sensor.

Gyrocompassing - The purpose of this experiment is to evaluate the accuracy of a precision gyrocompass which in turn may be used as a master reference for evaluating various other yaw sensing techniques such as body-mounted gyrocompasses, ion sensing, V/H sensing, etc. Furthermore, this experiment will evaluate the feasibility of using a gyrocompass for an autonomous navigation attitude reference. Gyrocompassing to determine vehicle yaw is a proven orbital technique. Programs which have used (or will use) some form of gyrocompass include Discoverer, Mercury, Nimbus, OGO, and Gemini. Of these programs, only Nimbus has reportedly included an attitude reference for qualitatively evaluating the gyrocompassing accuracy. Gyrocompass accuracy is a function of horizon sensor performance, gyro drift, and attitude control system operation. Additional precision gyrocompass experiments are needed with precise horizon sensor and gyro instrumentation and with a master reference for evaluating gyrocompass performance. The proposed approach using a two gimballed platform can be evaluated in one flight using either a star tracker or sun sensor as the master attitude reference. Other approaches could be examined in succeeding flights. If precision on the order of 0.1° is attained the gyrocompass could be used as a master attitude reference.

High Reliability Horizon Sensor - The objective of this experiment is to measure the inflight performance capability of high reliability horizon sensors. In particular this experiment is applicable to sensors with a null requirement of

1 to 5 degrees. Laboratory tests will provide an adequate test of the horizon sensor without the effects of anomalies. A flight test is required to evaluate the effect of atmospheric anomalies. Units have been and are being flown and data and performance obtained. In general the data obtained is not referenced against a precision reference, therefore the data is qualitative rather than quantitative. Flight evaluation of the most promising design concepts will be undertaken to establish if the sensor head will track and to evaluate its accuracy by using a precision horizon sensor.

Star Recognition - The object of this experiment is to evaluate the inflight capability of a star mapper system to automatically provide vehicle attitude information. Laboratory tests can be performed to establish the ultimate accuracy of star trackers and star mappers. Simulators can be built which provide relatively accurate star color and magnitude simulation. Stellar background light effects, exact solar radiation effects, and the effect of star clusters is not so easy to simulate. Flight test is required to provide the final evaluation of performance in recognizing a star (or stars) and providing the necessary attitude reference signals. In the experiment the selected star mapper system is placed into orbit on a vehicle using a star tracker system as a master reference. The transmitted data is evaluated to determine the capability of the star mapper to recognize star patterns, and to discriminate between stars and the accuracy of measurement. Very few star mappers are beyond the conceptual stages and none are to a hardware stage (other than breadboard). A development program of 3 or 4 flights for each type of sensor will be needed. In order, the flights will determine: (1) effectiveness of sensing technique, (2) effect of modifications and resulting accuracy, (3) final accuracy of complete system and computer.

Small Impulse Devices - The objective of this experiment is to determine the characteristics of small impulse thrusters when operated in a space environment. These thrusters are the result of design efforts to minimize on-off system limit cycles by providing small impulse characteristics. These devices will be used (1) as attitude control torques for small, long-term satellites whose orbits may not permit the use of passive control techniques, (2) as damping devices for passive control techniques, and (3) as vernier controls for large satellites requiring small limit cycles. The test requires a separate experimental package for each thruster design.

Optical Windows and Mirrors - The objective of this experiment is to quantitatively measure the optical degradation which occurs in windows and first surface mirrors which are exposed to the space environment for long periods of time. Proper performance of sealed optical systems requires high quality windows whose characteristics are fixed. The need for such windows is immediate. However, because some information is being gathered on other programs and some qualitative data can be gathered in the lab, this experiment is placed in Category B. The experimental package for test has six windows and one mirror. These will be exposed to the space environment and checked periodically for changes in transmissability and reflectivity characteristics. The test would be repeated to use different materials or modifications of original materials.

Bearings and Lubricants - The objective of the experiment is to verify the accuracy of ground test results in orbital flights. It is an important test area because of wide use. In general, ground testing is believed adequate except for the low-g and radiation effects. The bearings will operate continuously in two-week cycles. Daily measurements of friction effects will be made. Possibly 10 to 20 experiments could be performed with variations in types of lubricants, sizes of bearings, and loads. Tests are simple, requiring low data handling capability, and place minimum constraints on the payload. Experimental results are important since accuracy and endurance of many guidance and control devices is limited by bearings and lubricants.

5.4 Category C Experiments - Experiments selected for this grouping generally include devices where: (1) the development status and mission requirements are beyond the time scale of this study; (2) the performance and design of the device is highly dependent on the vehicle configuration; (3) the concept is highly specialized; or (4) ground testing is sufficient to prove the concept, but orbital test is required for operational verification of the device. A number of the suggested experiments can become prime experiments as future mission requirements are better defined or as other factors, listed in Table 5-2, which influence their secondary designation are resolved. Section 4 of Volume II contains a discussion concerning the device or technique and in most cases a general description of experiments that should be considered. A brief summary of each is given below.

Planet - Moon Vertical Sensor - The objective of this experiment is to evaluate the performance of an infrared lunar planet horizon sensor concept as compared with a precision reference system such as a star tracker. The device is needed to provide a local vertical reference when in the immediate vicinity of Mars, Venus, or the Moon.

Gravity Gradient Controls - Active Damping - This experiment is designed to determine the accuracy and libration damping capability of active control mechanisms on a gravity gradient oriented satellite of non-optimum inertia configuration. Certain mission requirements may define a need for gravity gradient stabilization of vehicles whose inertia configurations cannot be favorably

TABLE 5-2
CATEGORY C EXPERIMENTS – FACTORS DETERMINING SECONDARY DESIGNATION

EXPERIMENTS	BEYOND THE TIME SCALE OF THE STUDY – CONSIDERABLE NON-ORBITAL TEST REQUIRED FIRST	HIGHLY DEPENDENT ON VEHICLE CONFIGURATION	TECHNOLOGY AREA AND ASSOCIATED PROBLEMS NEED BETTER DEFINITION BEFORE ORBITAL TESTS CAN BE DEFINED	GROUND TESTING PROVES CONCEPT. ORBITAL TEST FOR VERIFICATION
1. Planet-Moon Vertical Sensor				√
2. Gravity Gradient Controls-Active Damping		√		
3. Automatic Landmark Tracking	√		√	
4. Microwave Radiometric Local Vertical Sensor	√		√	
5. Cryogenic Gyro	√			√
6. Temperature Rate Flight Control System		√	√	
7. Densitometers		√	√	
8. Rendezvous Sensors		√	√	
9. Fluid Systems			√	√
10. V/H Sensing	√		√	
11. Control Logic		√		√
12. Reaction Jets				√
13. Extravehicular Control		√	√	
14. Passive Control Techniques	√	√	√	
15. Space Environment Tests				√

augmented by extensible booms, etc. or whose missions require fast damping to the earth orientation after infrequent pointing to other attitudes. Active controls will then be required. Pulsed jets, reaction wheels and control gyros will provide active control sources capable of precision vehicle alignment in the presence of disturbance torques.

Automatic Landmark Tracking - The purpose of this experiment is to obtain scientific data on the characteristics of various types of earth landmarks. Development of the earth feature (passive) mode requires basic scientific data; the development of the active mode (beacons/reflectors) can be evaluated from high altitude aircraft. Flight tests at orbital altitudes will be required ultimately to determine accuracy and system performance.

Microwave Radiometric Local Vertical Sensor - The object of this experiment is to obtain scientific data on the characteristic of the earth's O_2 layer. Orbital tests are required if feasibility of the approach can be shown to be promising. Aircraft flight test can provide limited data for evaluation.

Cryogenic Gyro - This experiment is designed to evaluate the drift rate performance and remote start up capability of a cryogenic gyro. This device has high potential but equipment is not yet sufficiently developed to warrant a detailed experiment description at this time.

Temperature Rate Flight Control System - The object of this experiment is to determine if heating rate sensors (thermocouples) imbedded in a lifting hypersonic re-entry vehicle can provide sufficient information to the vehicle autopilot for control during re-entry, transition and equilibrium glide. The primary objective of this system is to avoid thermal and load factor constraints by flying a predetermined temperature rate boundary in the V/H plane. An experiment was recently flown on ASSET. Application of this concept must await advances in vehicle technology and a definition of mission requirements.

Densitometers - This experiment is proposed to evaluate the use of densitometers to obtain air data measurements in the presence of a plasma barrier. Mechanization problems are complex and for certain vehicles ablative products contaminate free stream measurements. This experiment requires a lifting hypersonic glide vehicle such as ASSET or the X-15 for test. Such a device would fill a prime need for an air data sensor in the re-entry environment.

Rendezvous Sensors - Suggested experiments include background noise and signal attenuation tests to determine the need for additional and advanced sensor development tests. This is a useful test area but it is extremely broad and, hence, it is difficult to define meaningful experiments. Gemini, Apollo and the space stations require rendezvous sensors and alternate experiments and techniques are being studied for these programs. Additional study and some correlation of test results from these programs are needed in order to define useful experiments.

Fluid Systems - The primary objective of this test is to examine the effects of the space environment on certain areas of fluid technology. Foremost will be the unique problems associated with the pumping of fluids in a zero-g field. The results of these tests will be used to determine the applicable uses of fluids in guidance and control of aerospace vehicles.

V/H Sensing - The object of this experiment is to obtain proof tests of the device at orbital altitudes and velocities. Applications include image motion compensation for photographic systems, navigation sensing and attitude reference functions. Ground and airplane testing can provide useful data but orbital testing is desirable since an optical system is viewing the earth through the atmosphere, clouds, etc. Equipment development status and a firm application are not yet sufficiently defined for orbital test.

Control Logic - The purpose of the experiment is to verify the adequacy of ground simulation for various control systems. Control of the vehicle by the experiment is required for these tests. Devices of this type are generally tailored to the specific vehicle involved. Although ground testing can provide a large percentage of the required data, the final proof test in an orbiting vehicle is desirable.

Reaction Jets - Orbital test of reaction jets is proposed to determine the jet thrusting characteristics in a vacuum environment and to provide a final proof test of the system. Both cold gas and hot gas jets could be evaluated.

Extravehicular Control - The object of this experiment is to evaluate the six-degree-of-freedom body dynamics and tether vibration modes of a tethered sensor package or simulated astronaut in the space environment. The information which would be obtained from this test would be valuable in planning further ground tests and full-scale astronaut extravehicular tests to be conducted on Gemini and Apollo flights.

Passive Control Techniques - This experiment would evaluate vehicle configurations designed to use natural forces for passive control. The four major passive control sources include gravity gradient, solar and aerodynamic pressures, and magnetic fields. Mariner IV contained a solar pressure experiment. Aerodynamic pressure control is vehicle dependent and is restricted to low orbital altitudes. The magnetic field has been used for damping on gravity gradient stabilization experiments. Useful experiments can be defined in each of these areas, but require a specific vehicle configuration.

Space Environment Tests - The object of these tests is to verify ground test results. Life tests are considered worthwhile in certain areas to increase confidence in the capability of new devices. Inherent confidence of a device can be increased by these tests, but a large number of tests are required to obtain a significant sample size and thereby obtain statistical reliability data. Difficulty in determining the cause of failure detracts from the usefulness of the tests.

6. EXPERIMENT PAYLOAD CONSIDERATIONS

6.1 Summary - This section summarizes the Category A and B experiment requirements, presents multiple experiment groupings based on selected common requirements, and shows that, with further iteration, these multiple experiment groups can be used to define preliminary mission and integrated payload design requirements. In addition, experiment implementation is discussed in terms of possible approaches for conducting an orbital test program. The three approaches considered include single experiment piggyback, multiple experiments piggyback and multiple experiments on a special vehicle. The advantages of conducting experiments on a manned vehicle are briefly discussed.

6.2 Experiment Requirements - Tables 6-1 and 6-2 summarize the Category A and B experiment requirements respectively. The data contained in these tables was abstracted from the experiment technical descriptions in Volume II which contains additional discussion on the requirements. It should be made clear that this data represents nominal requirements which were derived by assuming that each experiment could be performed exactly as desired. In general, the highest quality data will be obtained when the desired conditions are met; however, it is recognized that practical considerations such as the carrier vehicle or multiple experiment groupings will cause further trade-offs between experiment requirements, payload design and mission operations. In many cases, there is only a minor effect in test results due to changes in the experiment requirements. For example, shorter test times than indicated in the tables would provide useful data; however, longer test times are always desirable because the larger data sample would increase confidence in the test results.

6.3 Multiple Experiment Groupings - The data in Tables 6-1 and 6-2 can be used to define various experiment groups on the basis of common requirements. However, it is perhaps most instructive to group the experiments by orbit, orientation, master attitude reference and time duration so that broad mission and payload design requirements can be defined. Tables 6-3, 6-4 and 6-5 illustrate groupings by orbit and orientation, master attitude reference and test duration respectively. In each table, the fifteen Category A and B experiments are divided into three groups. For example, in Table 6-3, Group I assumes an orbit and orientation which satisfies eight of the fifteen experiments; Group II satisfies four of the fifteen; and Group III includes the remaining three experiments which are compatible with Group I, Group II or other orbital and attitude conditions. Note that all of the A and B experiments can be performed with the selected orbit and with a payload orientation system capable of providing earth-orbit plane and inertial alignments. Similar subdivisions are made in Tables 6-4 and 6-5 which consider master attitude reference and test duration requirements, respectively. Additional groupings based on other requirements are possible, although such groupings tend to lead into the definition of the subsystem support requirements. However, prior to defining such subsystem requirements, it is considered more desirable to use the groupings in Tables 6-3, 6-4 and 6-5 to further examine broad mission requirements.

By integrating across the groupings in the three tables, it is possible to define a set of conditions which is near optimum in the sense that all of the experiments can be conducted with the same payload. From the previous conclusion regarding orbit and orientation requirements and further examination of the master attitude reference and test duration tables, it is seen that the following conditions will satisfy all of the experiments:

Orbit: 300 N.M. altitude, near circular, near polar

Orientation: Earth-orbit plane and inertial

Master Attitude Reference: Gimballed Star Tracker and Sun Sensor

Test Duration: Three to six months.

In the above conditions, it has been assumed that the sensors used for Horizon

TABLE 6–1

SUMMARY OF CATEGORY A EXPERIMENT REQUIREMENTS

EXPERIMENT	ORBIT PARAMETERS			STABILIZATION			BASIC EXPERIMENT				TEST TIME		SPACE VEHICLE SUPPORT				DATA HANDLING			DEVELOPMENT		PRECISION GROUND TRACKING	EXPERIMENT MOUNTING	
	h (MM)	e	i (DEG.)	ORIENTATION	ATT. (DEG.)	ATT. RATE (DEG./SEC.)	LB.	$FT.^3$	WATTS PK.	WATTS AVG.	DURATION (NOM.)	OPERATE (NOM.)	ELECT. ENERGY (WATT-HR.)	TEMP. CONTROL (DEG. F)	MASTER ATT. REFERENCE	TIME REF.	NO. OF ANALOG PARAMETERS	NO. OF DIGITAL PARAMETERS	BEST ACCURACY REQ'D. (%)	TIME MONTHS	GATING ITEM		FIELD OF VIEW (CLEARANCE)	LOCATION (C.M., OR PROXIMITY)
1. Electrostatic Gyro	> 200	any	any	Solar-inertial or pure inertial (3 axes)	±2	≤ 0.05	20	.32	25	10	30 days	28 days	6800	30–80	Star Trackers	Relative	5	6	≥ 1.0	16	Suspension Electronics			√
2. Low g Accelerometer	> 300	< 0.01	any	Earth in p&r orbit plane in y	± 5	y ≤ 0.0005 r & p ≤ 0.05	36	1.2		36	> 1 mo.	5 days	300	30–100	None	Relative	5	4	≥ 1.0	17	Measurement Apparatus			√
3. Gravity Gradient Sensor	300 to 500	< 0.01	any	Earth-orbit plane (3 axes)	± 0.1	≤ 0.05	28	.74	53	53	3 days	1.5 hr.	135	0–140	Star Tracker	Absolute	13	5	≥ 1.0	17	Selection Low g Accelerometer	√		√
4. Earth Horizon Definition	100 to 600	< 0.01	> 70	Earth-orbit plane (3 axes)	y < 5 p&r < 1	≤ 0.1	284	5.2	145	135	2 wks.	9 hr.	8450	40–90	Star Tracker /Gyro	Absolute	21	5	≥ 1.0	14	Fabrication of Master Reference	√	√	
5. Horizon Sensor Accuracy	200 to 300	< 0.07	> 70	Earth-orbit plane (3 axes)	y < 5 p&r < 1	≤ 0.1	54	.7	82	80	2 wks.	9 hr.	4400	40–130	Star Tracker /Gyro	Absolute	18	5	≥ 1.0	12	Master Reference	√	√	
6. Gas Bearing Performance	> 200	any	any	any	any	≤ 0.1	23	0.3	21	4	4 days	3.3 hr.	30	0–120	None	None	19	3	≥ 1.0	15	Rotor Assembly			√
7. Star Characteristics	200 to 500	any	any	Pure inertial (3 axes)	± 0.1	≤ 0.1	32	1	12	10	3–6 mo.	20 hr.	102	0–135	Star Tracker	Absolute	12	4	≥ 1.0	14	Gimballed Detector System	√	√	

TABLE 6–2

SUMMARY OF CATEGORY B EXPERIMENT REQUIREMENTS

EXPERIMENT	ORBIT PARAMETERS			STABILIZATION			BASIC EXPERIMENT				TEST TIME		SPACE VEHICLE SUPPORT				DATA HANDLING			DEVELOPMENT		PRECISION GROUND TRACKING	EXPERIMENT MOUNTING	
	h (NM)	e	i (DEG.)	ORIENTATION	ATT. (DEG.)	ATT. RATE (DEG./SEC.)	LB.	$FT.^3$	WATTS PK.	WATTS AVG.	DURATION (NOM)	OPERATE (NOM.)	ELECT. ENERGY (WATT-HR.)	TEMP. CONTROL (DEG. F)	MASTER ATT. REFERENCE	TIME REF.	NO. OF ANALOG PARAMETERS	NO. OF DIGITAL PARAMETERS	BEST ACCURACY REQ'D. (%)	TIME MONTHS	GATING ITEM		FIELD OF VIEW (CLEARANCE)	LOCATION (C.M., OR PROXIMITY)
1. Gravity Gradient Controls-Passive Damping	300 to 500	< 0.01	any	Earth-orbit plane (3 axes)	± 30	≤ 0.1	35	1.2		2.5	1 day	20 hr.	50	–	Horizon Sensor & Gyrocompass (or Sun Sensor)	Relative	13	–	≥ 1.0	6	Vehicle Selection		√	√
2. Ion Attitude Sensing	150 to 3000	< 0.01	90	Earth-orbit plane (3 axes)	± 10 in p & y, ± 3 in r	≤ 0.1	24	.4		21	1 wk.	1 wk.	3528	40–130	Gyrocompass	Relative	8	1	≥ 1.0	7	Availability Gyrocompass Reference		√	
3. Gyrocompass-ing	150 to 300	< 0.01	any	Earth-orbit plane (3 axes)	± 2	≤ 0.1	21	.5	33	20	1 wk.	5 days	3600	40–130	Sun Sensor or Star Tracker	Relative	12	1	≥ 1.0	10	Master Reference			
4. High Reliability Horizon Sensor	200	> 0.01	90 (N.C.)	Earth (2 axes)	± 1	≤ 0.1	35	.6	72	70	3–6 mo.	9 hr.	3040	40–130	Horizon Sensor ($0.1°$ Acc.)	Relative	7	–	2.0	12	Development of Sensor		√	
5. Star Recognition	> 200	any	90	Pure inertial (3 axes)	± 1	≤ 0.05	35	.8	63	60	3 days	9 hrs.	500	0–150	Star Tracker Horizon Sensor	Absolute	13	3	≥ 1.0	12	Star Mapper Development	√	√	
6. Small Impulse Devices	> 150	any	any	any	any	≤ 0.1	16	.4	28	10	2 days	50 min.	14	–	None	Relative	8	–	≥ 1.0	10	Device & Vehicle Selection		√	√
7. Optical Windows and Mirrors	Van Allen Belts	any	any	Solar (2 axes) (N.C.)	± 30	N.C.	13	.2	40	14	6 mo.	9 hr./mo.	225/mo.	–	None	None	14	–	≥ 1.0	9			√	
8. Bearings and Lubricants	200 to 600	any	any	any	any	any	1.2	.02	13	6	> 6 mo.	14 day/mo.	2900/mo.	60–100	None	None	5	1	≥ 1.0	6				

Sensor Accuracy and Gyrocompassing tests can later be used for master attitude reference instrumentation. Further examination of the sub-system support requirements and payload design integration studies might show that such an "optimum" payload is indeed "non-optimum" from the viewpoint of cost, design complexity and ability to obtain useful test results. For example, consider the stabilization sub-system requirements. From Tables 6-1 and 6-2, the Low-G Accelerometer and the

TABLE 6-3
ORBIT AND ORIENTATION GROUPINGS

Experiment Title	Category
GROUP I	
Orbit: 300 nautical mile altitude, near circular, near polar. Orientation: Earth – orbit plane.	
Low-g Accelerometer	A
Gravity Gradient Sensor	A
Earth Horizon Definition	A
Horizon Sensor Accuracy	A
Gravity Gradient Controls- Passive Damping	B
Ion Attitude Sensing	B
Gyrocompassing	B
High Reliability Horizon Sensor	B
Star Recognition*	B
GROUP II	
Orbit: 300 nautical mile altitude, near circular, near polar. Orientation: Inertial	
Electrostatic Gyro	A
Star Characteristics	A
Star Recognition*	B
Optical Windows and Mirrors	B
GROUP III	
Orbit and orientation not critical – can be performed with Group I, II or other conditions.	
Gas Bearing Performance	A
Small Impulse Devices	B
Bearings and Lubricants	B

*An inertial orientation is preferred for initial test, but ultimately needs testing on an earth oriented payload.

TABLE 6-4

MASTER ATTITUDE REFERENCE GROUPINGS

		Category
GROUP I –	Star Tracker or Sensor*	
	Experiment Title	Category
	Electrostatic Gyro	A
	Gravity Gradient Sensor	A
	Earth Horizon Definition	A
	Horizon Sensor Accuracy	A
	Star Characteristics	A
	Gyrocompassing	B
	Star Recognition	B
GROUP II –	Horizon Sensor and/or Gyrocompass*	
	Gravity Gradient Controls- Passive Damping	B
	Ion Attitude Sensing	B
	High Reliability Horizon Sensors	B
GROUP III –	None Required	
	Low-g Accelerometer	A
	Gas Bearing Performance	A
	Small Impulse Devices	B
	Optical Windows and Mirrors	B
	Bearings and Lubricants	B

*Sun tracker or sensor may be used as a supplement or, in some cases, as the prime reference.

Gravity Gradient Sensor tests have the most stringent rate (0.0005°/sec) and attitude (0.1 deg) requirements. However, the majority of the remaining experiments can be conducted with rate and attitude control on the order of 0.1 deg/sec and 1 or 2 degrees, respectively. Hence, it appears impractical to design a complex (implies increased cost and decreased reliability) stabilization sub-system for one or two experiments when a much simpler sub-system would satisfy the majority of the experiments. A further example is provided by noting the column designated Experiment Mounting in Table 6-1. Four of the seven Category A experiments desire a location near the vehicle center of rotation to minimize the effects of vehicle angular motion. The remaining three experiments require special mounting for an

TABLE 6-5

TEST DURATION GROUPINGS

Group	Experiment Title	Category
GROUP I –	One Week or Less	
	Gravity Gradient Sensor	A
	Gas Bearing Performance	A
	Gravity Gradient Controls-Passive Damping	B
	Ion Attitude Sensing	B
	Gyrocompassing	B
	Star Recognition	B
	Small Impulse Devices	B
GROUP II –	Greater Than One Week But Less Than One Month	
	Electrostatic Gyro	A
	Low-g Accelerometer	A
	Earth Horizon Definition	A
	Horizon Sensor Accuracy	A
GROUP III –	Greater Than One Month	
	Star Characteristics	A
	High Reliability Horizon Sensors	B
	Optical Windows and Mirrors	B
	Bearings and Lubricants	B

unobstructed field of view to see the earth horizon or celestial sphere. When similar mounting requirements from the Category B experiments are added to those above, it becomes clear that practical payload design considerations do not permit all of the desired mounting conditions to be met with a single vehicle.

At the other extreme, an approach worthy of consideration is one in which a minimum set of conditions is used (implying minimum cost). One such approach might select experiments which do not require orientation and master attitude reference systems. However, in examining Tables 6-3 and 6-4, it is seen that only three experiments (Gas Bearing Performance, Small Impulse Devices, and Bearings and Lubricants) fit these conditions. Thus, it appears that to accommodate a

TABLE 6-6

INTEGRATED GROUPINGS – SELF CONTAINED PAYLOAD

GROUP I – Moderate Cost Payload

- Orbit: 110 nautical mile altitude, near circular, 30 degree inclination.
- Orientation: Earth-orbit plane.
- Master Attitude References: Horizon and Sun Sensors, Gyrocompass (40 lb., 1.2 $Ft.^3$)
- Duration: One week

Experiments	Lb.	$Ft.^3$	Watt-Hr.
Low-G Accelerometer	36	1.2	300
Gas Bearing Performance	23	0.3	30
Ion Attitude Sensing	24	0.4	3500
Gyrocompassing	21	0.5	3600
Totals	104	2.4	7430

GROUP II – Near Optimum Performance Payload

- Orbit: 250 nautical mile altitude, near circular, near polar.
- Orientation: Earth-orbit plane and inertial-orbit plane.
- Master Attitude Reference: Gimballed star tracker and Sun Sensor (50 lb., 1.8 $Ft.^3$)
- Duration: One to two months.

Experiments	Lb.	$Ft.^3$	Watt-Hr.
Electrostatic Gyro	20	0.4	6800
Earth Horizon Definition	284	5.2	8450
Horizon Sensor Accuracy	54	0.7	4400
Star Characteristics	32	1.0	100
Gravity Gradient Controls- Passive Damping	35	0.8	50
Star Recognition	35	0.8	500
Gyrocompassing	21	0.5	3600
Totals	481	9.4	23,900

reasonable number of experiments without excessive complexity, intermediate conditions between the two extremes discussed above should be examined.

Two integrated groupings which use intermediate conditions are illustrated in Table 6-6. Group I is similar to the minimum cost conditions and Group II is quite similar to the optimum performance conditions. In both groups all possible A and B experiments are not included. Rather, in Group I emphasis is placed on accommodating experiments within the orbit and short duration restrictions and which require an earth-orbit plane orientation. In Group II, only those experiments which have definite master attitude reference but only moderate attitude control requirements are included. The table also shows preliminary weight, volume and watt-hour estimates which may be used as broad indicators of payload integration and electrical power requirements. Further study regarding the supporting sub-system requirements, possible carrier vehicles, and payload integration is necessary to determine the practicality of implementing such multiple experiment groupings.

6.4 Implementation Studies - Various implementation approaches can be evaluated for conducting an orbital test program. Three approaches designated the single experiment piggyback concept, multiple experiments piggyback concept and multiple experiments special vehicle concept are discussed in the following paragraphs.

6.4.1 Single Experiment-Piggyback - The use of the single experiment piggyback concept was a primary objective of this study program. The advantages of this approach include simplicity and economy of testing, short development lead time and experiment adaptability to several carrier vehicles. Table 6-7 illustrates possible carrier vehicles which partially satisfy the gross requirements for orbit, orientation, duration and master attitude reference for the majority of Category A and B experiments. The experiments not shown in Table 6-7 either require a special vehicle (Gravity Gradient Controls) or can be performed on a wide variety of vehicles because they are not overly sensitive to the gross requirements used in the table. The experiments which are included in this latter group include Gas Bearing Performance, Small Impulse Devices, Optical Windows and Mirrors, and Bearings and Lubricants.

It should be recognized that each experiment requires additional support from the carrier vehicle subsystems. The effective use of the single experiment piggyback concept requires that the carrier vehicle supply the master attitude reference,

TABLE 6-7

SINGLE EXPERIMENT PIGGYBACK CONCEPT – POSSIBLE CARRIER VEHICLES

EXPERIMENTS	POSSIBLE CARRIERS	CARRIER SATISFIES GROSS REQM'T FOR: ORBIT	ORIENTATION	DURATION	MASTER ATTITUDE REFERENCE	REMARKS
Electrostatic Gyro	OAO AOSO	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Critical item is watt-hour requirement.
Low-G Accelerometer	Nimbus OGO Gemini	Yes Yes Yes	Yes Yes Yes	Yes Yes Yes	Not Required	Stabilization is a major requirement.
Gravity Gradient Sensor	Nimbus OGO Gemini	Yes Yes Yes	Yes Yes Yes	Yes Yes Yes	No No No	Stabilization and master attitude reference are crucial items.
Earth Horizon Definition and Horizon Sensor Accuracy	Gemini Discoverer Apollo Nimbus OGO	No Yes No Yes Yes	Yes Yes Yes Yes Yes	Yes ? Yes Yes Yes	No No ? No No	Master attitude reference is critical requirement. Manned vehicle may permit experiment simplification.
Star Characteristics and Star Recognition	OAO AOSO	Yes Yes	Yes ?	Yes Yes	Yes ?	Manned vehicle may permit experiment simplification.
Ion Attitude Sensing and Gyrocompassing	Nimbus Gemini OGO Discoverer	Yes No Yes Yes	Yes Yes Yes Yes	Yes Yes Yes Yes	Yes Yes Yes ?	Master attitude reference for precision Gyrocompass not available on these carriers.
High Reliability Horizon Sensor	Nimbus OGO	Yes Yes	Yes Yes	Yes Yes	Yes Yes	A number of other carriers are applicable.

power, data handling and storage, and telemetry functions. If these requirements cannot be met, the advantages of the piggyback concept are greatly reduced by the increased weight, volume and complexity of the experiment support equipment. Due to insufficient data, it was not possible to evaluate the carrier vehicle's capability to provide these supporting functions. However, as seen in Table 6-7, a number of the vehicles cannot provide the master attitude reference function. The worst case occurs when the experiment self-contained instrumentation and power system cause the package to be too large and heavy to go piggyback on the desired vehicle.

6.4.2 Multiple Experiments - Piggyback - The second approach, multiple experiments piggyback, has the advantage that experiments with common requirements can share the same supporting subsystems such as a star tracker master reference, electrical power, data handling, telemetry, etc. The major disadvantage is in integrating the experiment package with the carrier vehicle.

Candidate carrier vehicles for this approach include the Saturn IB and V, Gemini, Apollo, and Discoverer. Once in orbit, the multiple experiment package could remain with the carrier vehicle or it could be ejected and perform as a self-contained unit. From the viewpoint of payload cost and complexity, the preferred approach is to remain with the carrier vehicle since the vehicle stabilization and possibly other supporting subsystems can be used. However, mission duration as well as payload mounting and field-of-view requirements are sure to be compromised for some of the experiments. For example, if the experiment payload is mounted in the Saturn vehicle instrumentation compartment, present information implies a total mission duration on the order of days and a stabilization duration on the order of hours. Additionally, with this mounting on Saturn, it is difficult to conduct an experiment which has field-of-view requirements. One approach for conducting experiments on Saturn is to incorporate those experiments which are of short duration and which do not require orientation and attitude reference measurements. Assuming this approach is used, candidate Category A and B experiments for Saturn include Gas Bearing Performance and Small Impulse Devices. Other experiments could be designed specifically for a Saturn payload.

6.4.3 Multiple Experiments - Special Vehicle - The third approach, multiple experiments on a special vehicle, is quite similar to the second approach where the multiple experiments piggyback payload is ejected from the carrier vehicle. The major advantage in this approach is that the experiment payload designer does not operate within the constraints imposed by the carrier vehicle on a piggyback payload, i.e., the designer can optimize the payload to satisfy the most desirable experiment conditions. Of course, the significant disadvantage is the additional cost for the launch vehicle. The multiple experiment groups illustrated in Table 6-6 are examples of experiments that might be conducted with the two approaches, assuming a self-contained payload is used in each case. In this table, Group I is compatible with the Saturn vehicle as a piggyback while Group II requires a special launch vehicle such as Thor-Delta.

6.5 Manned Vehicle Advantages - A single or multiple experiments package which remains with the manned vehicle (Gemini, Apollo, Space Station) is attractive because of the chance to use man's unique capabilities in setting up the experiment. Additionally, the test data can be recovered and, possibly, limited experiment equipment such as optical windows, etc. might be returned. A number of the Category A experiments are quite complex, especially those requiring precision star tracking from an earth-oriented vehicle. In these experiments, the use of man's ability to recognize star patterns and identify specific stars to point a star tracker (or vehicle) would be a significant step toward simplifying the experiments. Another significant contribution which man can make is in programming or sequencing the experiment, thus simplifying the automatic programmer. Given appropriate displays, man can also re-program experiments or phases of an experiment when the data obtained is questionable or is obviously in error. Finally, man's contribution as a general observer can be of significant value for most of the experiments. For example, he can examine optical surfaces and other equipment and also report on time to acquire, cloud conditions, vehicle angular motion, etc. Additional study regarding the advantages and disadvantages of man is needed prior to recommending that specific experiments be performed on a manned vehicle.

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