THE IMPORTANCE OF ENVIRONMENTAL TESTING INCLUDING EXPERIENCE WITH THE ARCAS-ROBIN SYSTEM

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2

INTRODUCTION

The testing of flight spececraft under simulated space conditions is used to confirm the analyses and assumptions of spacecraft design. This general approach has wide acceptance. The problem is to select a test program within the allocation of funds and the availability of facilities and manpower and to answer the following questions:

(1) What types of tests will be conducted on the complete system and subsystems?

(2) What method will be used to simulate the space environment?

(3) What test levels will be used?

The emphasis of this paper is on the selection of an environmental test plan that will result in the development of a reliable system for obtaining atmospheric measurements. First, the availability of facilities and their capability of providing a simulated environment for a falling-sphere system will be considered; then, the types of tests and test levels that have resulted in the development of successful flight systems. Finally, some techniques that can be used to simulate the environment of an inflatable falling sphere will be considered.

FACILITIES

The facilities at the Langley Research Center that can be used in an environmental test program for inflatable falling spheres are in the following categories:

First are the thermal vacuum and vacuum facilities. By utilizing one or more of the 16 facilities in this category, a system can be tested at the pressure altitude of its flight environment. Several of these facilities are capable of producing more than one condition. For example, a system could be operated under the pressure altitude, temperature range, and solar radiation that it experiences during flight. Another facility is capable of subjecting a system to the combined effect of a pressure altitude, a range of temperatures, and vibrations. Many of the facilities allow for the installation of special equipment to obtain a special condition on a system. For example, in a test that will be discussed subsequently, an airlock was installed inside one of the vacuum facilities to maintain the system being tested at sea-level pressure during the hours that are required to pump the facility to the test condition.

The next category, vibration and shaker facilities, also includes the equipment needed to perform acceleration tests. These facilities are used to provide the environment that a system would experience due to ground handling, rocket flight, and separation of the spacecraft from the rocket motor.

The balancing equipment and spin tables are used to subject the system to the spin rate provided by rocket flight, to balance the spacecraft, and to subject the system to a steady-state acceleration.

Solar simulation equipment is available and can be used with several of the vacuum facilities to obtain a combined effect.

There are numerous pieces of equipment in the fatigue and load testing category for use in testing the structural integrity of a system.

The descriptions here have been brief, but there appear to be sufficient facilities available to allow for the design of an experimental test program that will give confidence that an inflatable-falling-sphere system will survive the rocket launch and operate in its environment. A detailed listing of the environmental test equipment at the Langley Research Center and their characteristics is available in reference 1.

TYPES OF TESTS AND TEST LEVELS

With the facilities available, attention can now be directed to the following question: What types of tests and test levels should be incorporated in an environmental test plan? The appendix outlines a general test plan that is desirable in the development of a flight system and the types of tests and activities within the elements of the test plan. Obviously, each system must be considered individually with variations made in the test plan and selection of the types of tests based on the following criteria:

(1) Mission criticality

(2) Level of design uncertainty

(3) Level of environmental uncertainty

(4) Resources available

One approach to the testing level that has resulted in a high rate of success is documented in reference 2. The engineering test model (ETM) systems and/or prototype systems are tested at stress levels up to $1\frac{1}{2}$ times the expected environments of launch or space. The flight systems are tested under the expected environments of launch or space.

SIMULATION TECHNIQUES

The final question to be considered is how to simulate the environment for an inflatable falling sphere. There is no single answer to this question. However, some examples are available from a limited test program conducted at the Langley Research Center during 1964 on the Arcas-Robin system. These examples were functional tests in a simulated environment designed to aid in identifying the failure modes of an Arcas-Robin system.

The Arcas-Robin system is a 1-meter-diameter, 1/2-mil Mylar inflatable sphere designed to be carried to release altitude by a small rocket motor. The Robin sphere used in this test program had an internal corner reflector for radar tracking. The four basic functions that must take place in order for the system to function properly are illustrated in figure 1. First, the separation charge must fire and give the nose cone an increase in velocity. The next function is the removal of the nose-cone aft bulkhead by a lanyard that is permanently attached to the rocket motor. Removal of the bulkhead allows the next function, egress of the inflatable sphere from the nose cone, to occur. Finally, the sphere inflation capsule must function to inflate the sphere. Each basic function also has a series of subfunctions upon which it is dependent. These functions will be considered in more detail after a description of the three series of tests conducted on the Arcas-Robin system.

The first and second series of tests were conducted in a 5-foot-diameter, 10-foot-long thermal vacuum facility. The capabilities of this facility are as follows:

(1) A pressure of 1×10^{-6} torr (or a pressure altitude of approximately 650 000 feet)

(2) A temperature range of -320° F to 600° F

(3) A solar simulator which is a 15-kW carbon arc light

The tests in this facility consisted of mechanically removing the bulkhead from the Arcas nose cone. This procedure allowed the Robin sphere to egress and inflate. The test environment provided was a pressure of 64×10^{-3} torr and a solar simulator. The pressure utilized for these tests, 64×10^{-3} torr, can be achieved in 30 to 45 minutes. Two glass side ports and a 5-foot-diameter glass door permitted high-speed photographic coverage of the tests, as well as visual inspection of the inflated sphere. After sphere deployment, the pressure in this vacuum chamber was increased to 8.3 torr over the average time that the sphere experiences this pressure change in flight.

The results of the first series of tests are presented in table I. All six spheres ruptured during inflation.

Experience gained during the development of the Echo satellite indicated that the most likely cause of failure was an excessive rate of inflation caused by residual air trapped in the Robin sphere during packing. This cause of failure was easily eliminated by restricting the packing volume from 40 cubic inches to 22 cubic inches, and another series of tests was conducted on this modified system to evaluate the inflation system. Figure 2(a) is an illustration of the complete assembly of the standard sphere as used in the first series of tests, figure 2(b) shows the modified assembly, and figure 3 illustrates the modified deployment sequence.

The results of the second series of tests are presented in table II. The inflation capsule was omitted from tests 1 and 2 in order to evaluate the effect of residual air on inflation. All four tests were successful.

The third series of tests was conducted in the 60-foot vacuum sphere. This facility provided the space necessary to separate the nose cone from a dummy rocket motor during free fall by using the flight-separation device and to deploy and inflate the sphere before it contacted the walls of the test facility. An airlock was designed and installed in the facility to keep the Arcas-Robin system at sea-level pressure during the hours required to reach the test condition. The airlock was also designed to simulate the real-time altitude change of the Arcas-Robin system during the rocket flight. These tests were designed to obtain additional information on the reliability of the inflation system of the Robin sphere. (See fig. 4.) They also provided information about the relative position of the rocket motor, the nose cone, and the inflating sphere during separation. The results of the six tests conducted in this series are shown in table III. An analysis of the failures showed that the inflation capsule failed to function properly. In one test (3), all systems functioned properly.

An analysis of failure mode and effects has been prepared on the Arcas-Robin system in order to identify the single-point failures that are critical to mission success, to list the possible failures and the effects, and to aid in eliminating similar problem areas in future inflatable-sphere systems. The portion of that analysis identifying the failure modes of the Robin sphere is summarized in table IV. In this table it should be noted that the inflation system of the Robin sphere has five components, and each component has a serious malfunction associated with its operation. A malfunction of any one of these components could result in the failure of the Robin sphere to obtain useful data. The situation is complicated further because all the malfunctions support each other. This type of analysis should be performed on future inflatable falling-sphere systems to minimize malfunctions and to avoid placing an unreliable system into general use.

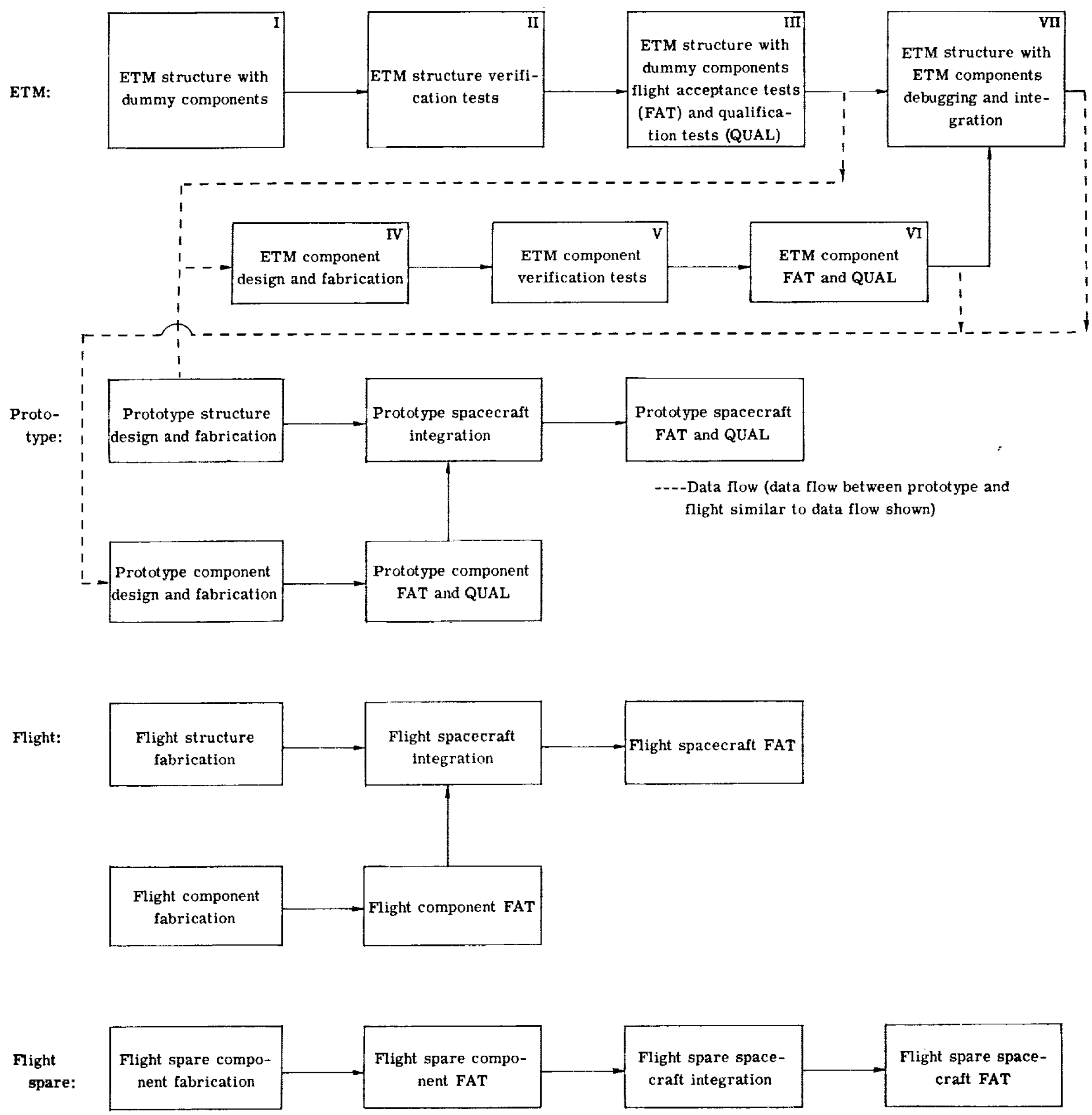
CONCLUDING REMARKS

The tests described here are only indications of what can be done with existing facilities to simulate the environment of a falling-sphere system. The justification for expenditure of resources in performing environmental tests is that insufficient design data are available to predict that the system will operate satisfactorily in its environment. The use of available facilities to conduct a well-planned environmental testing program can, for the most part, limit failures in the system to failures during environmental tests where instrumentation and high-speed photography in a controlled environment can be used to provide the data needed to identify the cause of failure. This method will give the designer the information needed to provide a reliable system for obtaining meteorological measurements.

APPENDIX

TEST PLAN

Flow Chart: Engineering Test Model (ETM), Prototype, Flight, and Flight Spare



Tests and Activities Within Elements of the Test Plan

I. ETM structure With Dummy Components
   A. Integration of structural members
   B. Integration of dummy components (fit check, interference check, alinement, etc.)

II. ETM Structural Verification Tests
   A. Vibration survey for structural design verification (resonance survey)
   B. Structural integrity (bending, compression, etc.)

III. ETM Structure With Dummy Component Flight Acceptance Tests (FAT) and Qualification Tests (QUAL)
   A. Vibration, shock, and acceleration tests
      1. Qualifies structural design
      2. Develop transmissibilities for ETM component design considerations

IV. ETM Component Design and Fabrication
   A. Apply data from III

V. ETM Component Verification Tests (Subsystem)
   A. Verifies and/or improves design concepts or intent
   B. Examples of tests
      1. Antenna pattern
      2. Pyrotechnic
      3. Despin
      4. Panel or boom deployment
      5. Spinup
      6. EMI (electromagnetic interference)

VI. ETM Component Flight Acceptance Tests and Qualification Tests
   A. Vibration, shock, acceleration, decompression, and thermal vacuum (FAT followed by QUAL)

VII. ETM Structure With ETM Components Integration, Debug, and Verification
   A. Physical electrical and mechanical capabilities and interfaces verified and resolved
   B. Operational compatibilities between components and between subsystems determined
   C. Compatibility of spacecraft and checkout equipment evaluated
   D. Subsystem and spacecraft response to command signals evaluated
   E. Refer to item V for test examples plus
      1. Alinement tests
      2. Heat-shield fit and ejection
      3. Physical parameters (weight center of gravity balance, moment of inertia)

NOTE: Similar activities take place with the prototype, flight, and flight spares.

REFERENCES

1. Clevenson, Sherman A.; and MacConochie, Ian O.: Characteristics of Environmental Test Equipment at the Langley Research Center. NASA TM X-1129, 1965.

2. New, John C.; and Timmins, A. R.: Effectiveness of Environment-Simulation Testing for Spacecraft. NASA TN D-4009, 1967.

TABLE I.- STANDARD DEPLOYMENT

[First test series; 5-foot-diameter, 10-foot-long thermal vacuum facility]

Test	Test pressure, torr	Sphere description	Inflation system	Remarks
1	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of iso-pentane	Sphere burst immediately with a tear developing from pole to pole
2	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of iso-pentane	2-inch-long tear in sphere. Inflated to full size but collapsed after $1\frac{1}{2}$ minutes
3	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of iso-pentane	3-inch-long tears in sphere. Inflated to full size but collapsed in less than 1 minute
4	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with air	Sphere inflated to full size by residual air. Sealed inflation capsule, no iso-pentane inside, broke through sphere wall
5	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of iso-pentane	Sphere burst immediately with a tear developing from pole to pole
6	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of iso-pentane	Sphere burst immediately with a tear developing from pole to pole

TABLE II.- MODIFIED DEPLOYMENT

[Second test series; 5-foot-diameter, 10-foot-long thermal vacuum facility]

Test	Test pressure, torr	Sphere description	Inflation system	Remarks
1	64×10^{-3}	Standard 1-meter-diameter sphere	Air trapped in sphere during folding	Sphere inflated to 1/4 size with residual air
2	64×10^{-3}	Standard 1-meter-diameter sphere	Air trapped in sphere during folding	Sphere inflated to 1/4 size with residual air
3	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of iso-pentane	Sphere inflated to full size in approximately 1/4 sec and maintained a stressed skin to a pressure of 8.3 torr
4	64×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of iso-pentane	Sphere inflated to full size in approximately 1/4 sec and maintained a stressed skin to a pressure of 8.3 torr

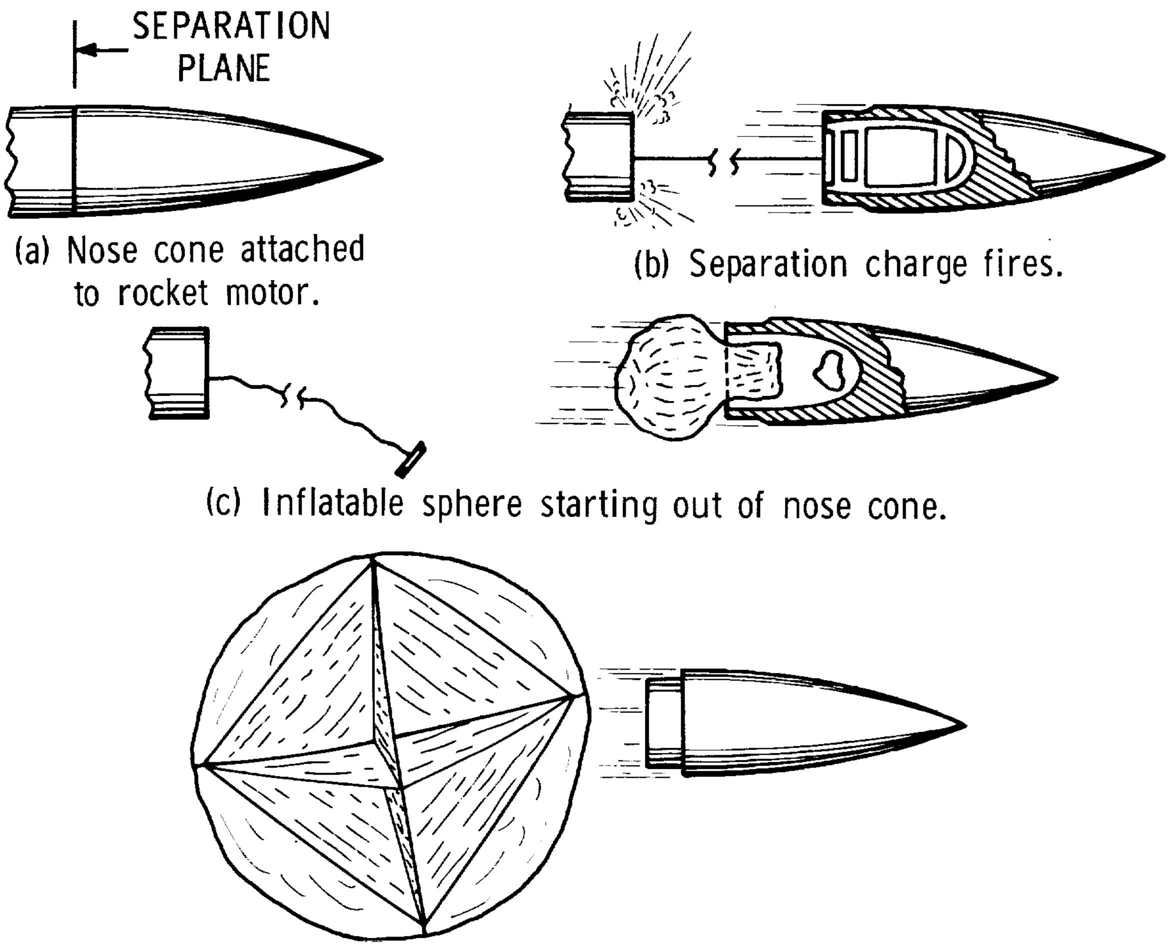
TABLE III.- MODIFIED DEPLOYMENT

[Third test series; 60-foot vacuum sphere]

Test	Test pressure, torr	Sphere description	Inflation system	Remarks
1	8.9×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of isopentane	Sphere did not inflate immediately because isopentane-capsule cap did not come off. Cap remained on capsule, but isopentane leaked into sphere over a 10-minute period and inflated it.
2	8.9×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of isopentane	Sphere did not inflate immediately because isopentane-capsule cap did not come off. Cap remained on capsule, but isopentane leaked into sphere over a 5-minute period and inflated it.
3	8.9×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of isopentane	This sphere inflated to full size immediately. Isopentane capsule functioned correctly. Sphere remained inflated to a pressure of 8.3 torr.
4	8.9×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of isopentane	Sphere did not inflate immediately. Cap came off inflation capsule after $1\frac{1}{2}$ minutes and sphere inflated to full size. Sphere remained inflated to a pressure of 8.3 torr. Steel lanyard between booster and nose cone broke in pulling bulkhead from nose cone.
5	8.9×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of isopentane	Deployment of the sphere was good, but the sphere fall rate was retarded by the snapback of the lanyard system. The dummy rocket motor overtook and hit the sphere. The cap did not come off the inflation capsule immediately, but inflation did occur in approximately $2\frac{1}{2}$ minutes. The sphere remained inflated to a pressure of 8.3 torr.
6	8.9×10^{-3}	Standard 1-meter-diameter sphere	Std. aluminum capsule with 35 cc of isopentane	Steel lanyard assembly broke at the dummy rocket motor. The sphere egressed from the nose cone, but the cap stayed on the inflation capsule, and the sphere did not inflate.

TABLE IV.- SUMMARY ANALYSIS OF FAILURE MODE AND EFFECTS FOR ROBIN SPHERE

Component	Function	Malfunction	Cause	Effect	Remarks
Mylar skin of Robin sphere	Contain inflation media and keep spherical shape	Leak	1. Pin holes due to handling or manufacturing. 2. Burn holes from separation charge. 3. Too rapid inflation causing structural damage. 4. Puncture from contacting the rocket motor or separating parts. 5. Sphere inflates out of nose cone contacting the metal rim of the nose cone.	Sphere failure or loss of data accuracy	Several instances were noted for the first three causes of failure. In approximately 1/3 of the tests the steel lanyard that removes the nose-cone bulkhead broke away from the rocket motor; in one of these instances the lanyard contacted the sphere causing a 1-inch long puncture. In the case of cause 5, the extent and cause of damage have not been determined.
Inflation-capsule container	Contain inflation media	Leak	Damage or assembly.	Sphere rupture	No incidents during these tests.
	Meter flow	1. No flow or slow flow 2. Flow too rapid	Freeze. Orifice size.	1. Partial inflation 2. Sphere rupture	Freezing noted in tests. No incidents of orifice problem.
Inflation media	Pressurize sphere	Insufficient pressure	Freeze or quantity too small.	Partial inflation	Freezing noted in tests. No incidents of quantity problem.
Inflation-capsule cap	Hold seal	1. Premature release 2. Stuck	Tolerance or damage.	1. Sphere rupture 2. No inflation	Tolerance noted to contribute to cap sticking.
Inflation-capsule pillow	Force cap off	1. Premature operation	Vacuum used during packing.	1. Sphere rupture	No incidents of premature operation.
		2. Insufficient force	Stroke too short. Not enough air. Leak in pillow.	2. No inflation	Insufficient force considered prime cause of inflation-capsule failure.
Inflation-capsule rubber gasket	Seal orifice	1. Leak	Improper assembly.	1. Sphere	No incidents of leaks.
		2. Orifice sealed with cap off	Rubber extruded into orifice. Rubber adheres to container.	2. No inflation	Extruding into orifice and adhering to container contribute to capsule failure.



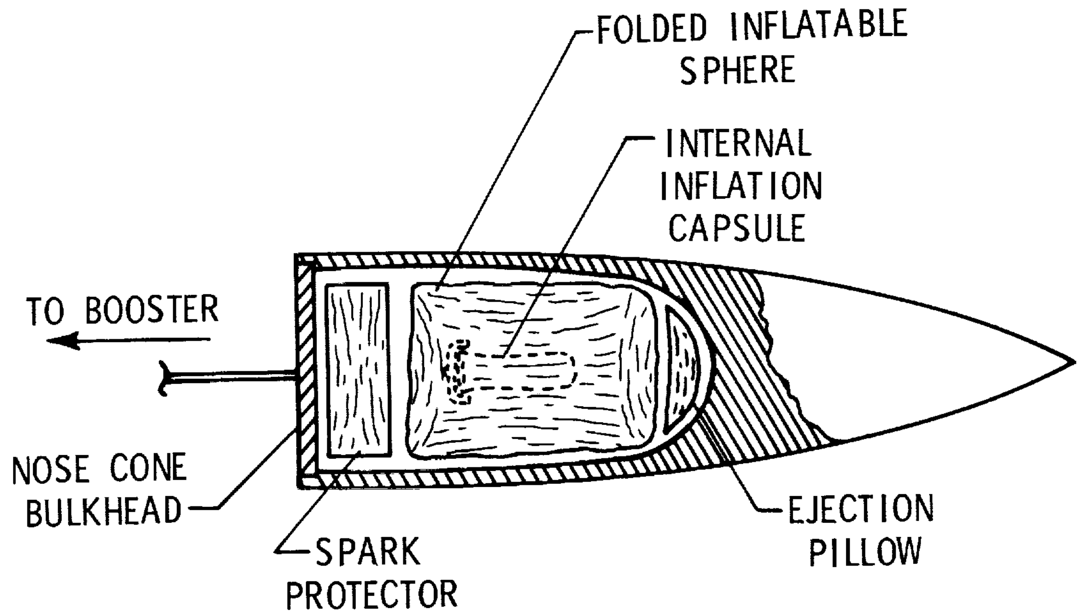
(a) Nose cone attached to rocket motor.

(b) Separation charge fires.

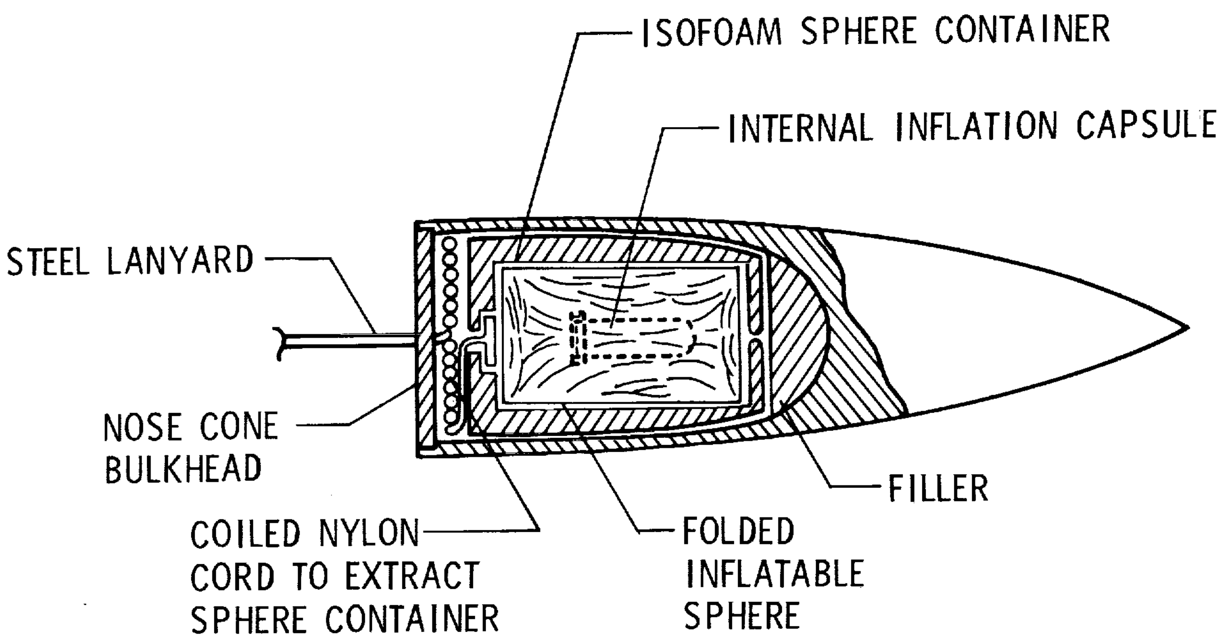
(c) Inflatable sphere starting out of nose cone.

(d) Sphere out and inflated.

Figure 1.- Sketch of standard Arcas-Robin deployment sequence.

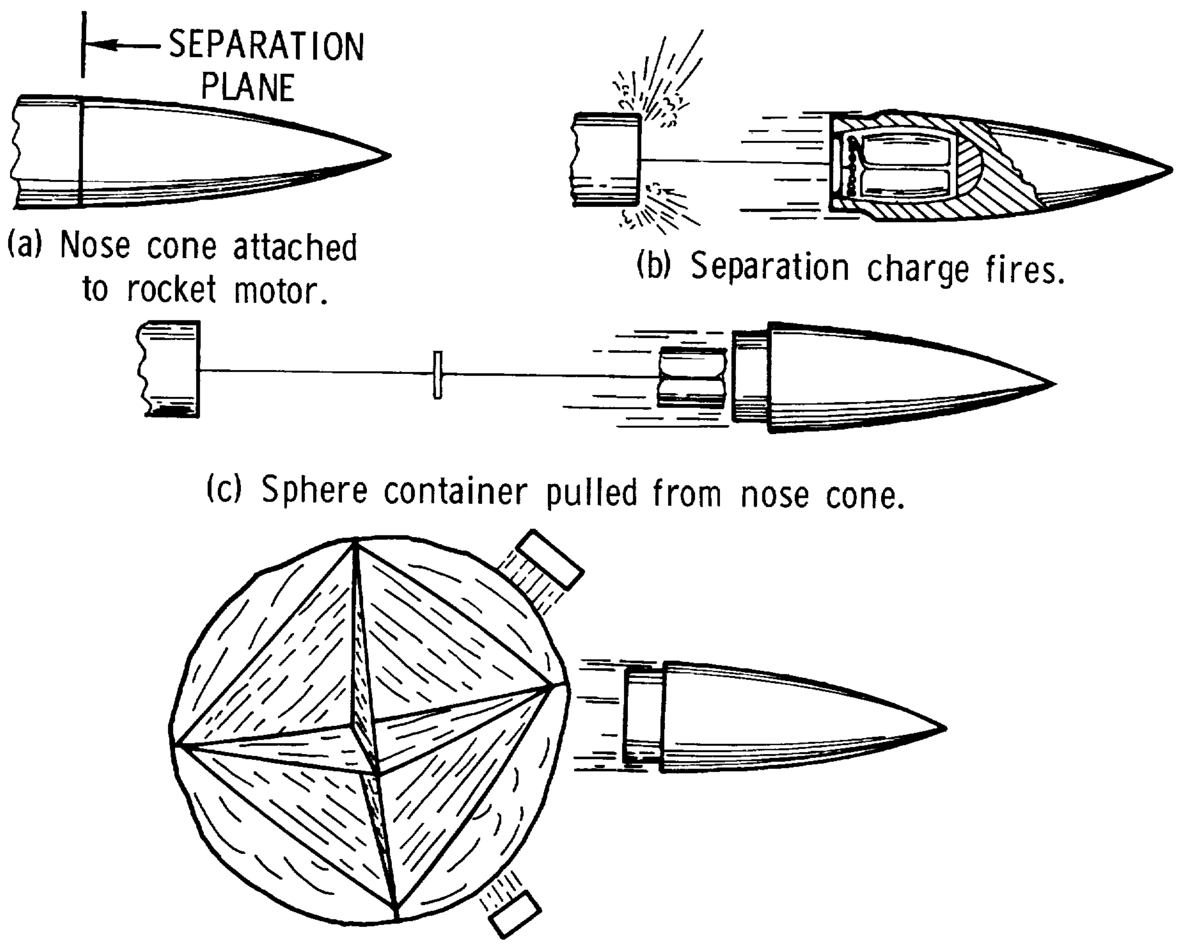


(a) Standard system.



(b) Modified system.

Figure 2.- Standard and modified Arcas-Robin payload assembly.



(a) Nose cone attached to rocket motor.

(b) Separation charge fires.

(c) Sphere container pulled from nose cone.

(d) Container separates and sphere inflates.

Figure 3.- Modified deployment sequence.

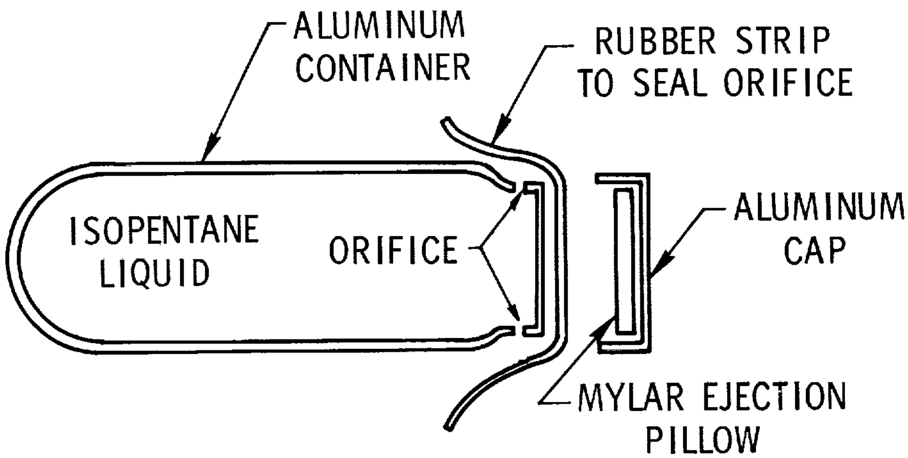


Figure 4.- Sketch of Arcas-Robin inflation capsule.