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TECHNICAL NOTE

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VANGUARD I SATELLITE STRUCTURE AND SEPARATION MECHANISM

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SUMMARY

A reevaluation of the Vanguard program objectives in January 1957 resulted in the production of the Vanguard I Satellite, a 6.44-inch-diameter, 3.25-pound sphere with six equally spaced solar cell clusters and six equally spaced antennas mounted on its surface. Experiment requirements necessitated the development of a mechanism to separate the satellite from the third-stage rocket. On the basis of the existing standard separation mechanism, a strap pull-pin girth-ring arrangement was developed. Both the satellite and the separation mechanism were fully tested prior to flight. Successful orbiting and flight operation proved the adequacy of the design.

CONTENTS

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INTRODUCTION

The reevaluation of the Vanguard program objectives in January 1957 resulted in a decision to redesign the "Minimal Satellite" (Figure 1) which was to be flown in the testing phase of the launch vehicle program. The new payload for the Test Vehicle (TV) Series included two tracking transmitters: one solar-powered, and one battery-powered. The separated satellite was symmetrical about any axis. In order to meet these new requirements the satellite structure was redesigned and a new method of satellite holddown and separation was developed.

SATELLITE STRUCTURE

Design

The design of the satellite structure was based upon five major considerations: (1) requirements and objectives of the experiments, (2) vehicle compatibility, (3) flight and orbital environmental conditions, (4) fabrication techniques, and (5) schedule requirements.

The experiment required an internal package containing seven mercury-cell batteries (in a hermetically sealed container), two tracking transmitters, a temperature-sensitive crystal, and six clusters of solar cells on the spherical satellite surface. The solar cells were equally spaced over the spherical surface and the crystal was located as close to the solar-powered tracking transmitter as possible. Six antennas were located on the satellite, at 90° intervals: the four antennas for the battery-powered transmitter in a plane; and the two for the solar-powered transmitter perpendicular to this plane. The structure supporting the internal package had to provide the lowest possible thermal conduction from the shell and radiation heat transfer from the shell to the internal package had to be minimized. This shell had to fit into the launch vehicle on the existing mounting structure. The satellite was designed to withstand the flight environmental conditions of shock, vibration, acceleration, rotation, and aerodynamic heating, and to withstand the orbital environmental conditions of temperature, vacuum, and possible erosion.

The time schedule for designing, fabricating, and testing the satellite was extremely short; therefore, the units were fabricated in the shops of the Naval Research Laboratory. Since the shops were not equipped to spin magnesium hemispheres, it was necessary to use aluminum at a slight weight disadvantage.

The Vanguard I satellite design fullfilled all of the requirements. The resultant satellite (Figures 2 and 3) can be described as follows: the sphere is an aluminum shell, approximately 6.5 inches in diameter, consisting of two hemispheres joined at the equator by a reinforcing ring; the lower hemisphere is riveted to the ring and the upper hemisphere is secured with small screws. When the sphere is located on the separation device, rotation is prevented by three pins that project from the flange of the separation-mechanism sleeve. These pins go through a doubler riveted to the inner surface of the satellite shell. At the north pole of the sphere are two small tracks which locate the separation-device holddown strap centrally on the crown of the sphere. The strap follows the spherical surface past the equator, then connects with the turnbuckle-toggle, which fits under the girth rings. Six antennas project 12 inches from the surface of the sphere: three in the upper section and three in the lower. The antenna axes are mutually perpendicular and pass through the center of the sphere. Between each two antennas a solar-cell arrangement is mounted directly on the spherical shell with small screws. Each antenna is 5/16 inch in outside diameter with a 0.020-inch wall, and is made of 6061T6 aluminum alloy.

A container inside the sphere holds the Mallory mercury cells and two transmitters. These cells power one transmitter, which is mounted above them. The second transmitter, mounted below, is powered by the solar cells on the satellite. This entire subassembly is supported inside the sphere by Kel-F support material. The base is supported by three vertical columns, the sides by four equally spaced columns, and the top by one adjustable column. The latter accommodates various battery package sizes. Located centrally between the three base columns is a holder for the solar-powered Minitrack transmitter crystal. Phasing harnesses are attached to the inside surface of the sphere and an antenna-matching network is placed at each antenna. A fully instrumented Vanguard I satellite weighs approximately 3.25 pounds. The weight of the separation device is slightly over one pound. (Appendix A presents a summary of satellite and separation-device weights.)

Fabrication

The satellite structure, fabricated by standard metal-working and machine-shop techniques at the NRL, consisted of hemispheric sections spun from 0.032-inch 5052S aluminum alloy. After spinning, the shells were stress-relieved and prepolished, and final machining operations were performed. After machining and installation of the equatorial joining ring the hemispheres were polished to a mirror finish.

The Kel-F support pieces, crystal mounting, antenna cups and caps, and internal package pieces were all machined from bar stock. Drill jigs and fixtures were used to insure interchangeability of parts and proper alignment. The U. S. Army Signal Research and Development Laboratory at Fort Monmouth, New Jersey supplied the drill jigs and the solar-cell assemblies for the satellite.

The inner package, battery and transmitter cylinder, and antenna cups and caps were made of aluminum alloy (5052S) and plated as follows: a base coat of zinc; copper; cadmium; silver; and finally solder plate. The solder plate was localized at the end of the battery cylinder and at the diaphragm separating the batteries and transmitter. The Kel-F support pieces were vacuum-plated with gold to reduce radiant heat transfer.

The two transmitters and the batteries were all potted with a foam-in-place plastic (Eccofoam FP), which had a density of approximately 10 to 12 pounds per cubic foot.

Testing

The structural testing of the Vanguard I satellite consisted of prototype tests (components, subassemblies, and assemblies) and flight-unit tests (complete assembly). Components and subassemblies (e.g., antennas, antenna insulating bushings, and Kel-F support pieces) were statically loaded to determine structural parameters, first at room temperature and then at 150°C. These static loads were increased from zero to loads which simulated 75-g steady-state acceleration (a 40-g maximum being expected in flight). The completely assembled structural prototype underwent a series of tests specified by the Environmental Sub-Committee of the Vanguard Science Program Committee.* The series of tests consisted of high-level vibration, acceleration, and thermal vacuum tests. The flight units underwent this series at reduced levels to minimize fatiguing of satellite components.

*Environmental Sub-Committee of the Science Program Committee of Project Vanguard, Mr. Herman E. LaGow, Chairman, "Environmental Testing of Project Vanguard Satellites," U. S. Naval Research Laboratory, 1956

SATELLITE SEPARATION MECHANISM

Design

Initially three methods of adapting the standard separation mechanism* for separating the Vanguard I satellite were considered: (1) a strap and explosive-bolt method, (2) a strap and pull-pin method, and (3) a strap, pull-pin, and girth-ring method. All three methods were investigated and the strap, pull-pin, and girth-ring method was chosen as the most reliable (see Figures 4 and 5).

Developmental work on the mechanism was done by Vanguard personnel. A prototype, drawings, and specifications were submitted to the Raymond Engineering Laboratories of Middletown, Connecticut so that expeditious modification of six standard units could be undertaken. The modifications consisted of (1) removing unnecessary components from the standard mechanism (release spring assembly and mechanism), (2) altering the internal configuration at the base of the mechanism to insure against buckling of the explosive motors, and (3) manufacturing the new release device consisting of strap, girth rings, and separation sleeve.

Operation

The mechanism is armed and fired by utilizing the acceleration characteristics of the Vanguard third-stage rocket. The operation of the separation mechanism can be described as follows: If an acceleration of approximately 12 g or more is applied for over two seconds, the timer will run for an additional ten seconds to a stop on the g-weight arm (if 12 g's or more is applied for less than two seconds, the unit will reset itself). When the g level is reduced below approximately 12 g's at third-stage burnout, the timer will start and run approximately 30 seconds. At the end of this period the timer arm closes the two firing circuits thereby connecting the batteries through the caterpillar motors (explosive motors), which expand, pulling the holddown pins in, and releasing the girth rings (Figures 4 and 6). The strap, which is contained by the girth rings when assembled to the satellite, is torqued to provide a tensile load of 100 pounds which is required to hold the satellite in position under flight environmental conditions. Upon release the strap springs off the crown of the sphere. Three small leaf springs, located directly under the sphere on the separation sleeve, separate the sphere from the third stage with a differential velocity of approximately one foot per second.

*Baumann, R. C. "Project Vanguard Satellite Separation Mechanisms," NASA Technical Note D-497, 1960

This operation sequence was not arbitrarily derived. The two-second arming time with 12 g or more acceleration insures that premature firing will not be caused by either shock or vibration. The additional ten-second arming time to reach the stop on the g-weight arm insures that slight variations in third-stage rocket acceleration will not cause premature separation by releasing the timer arm from the g-weight arm and allowing the firing sequence to be completed.

Testing

Testing of the standard separation mechanism may be divided into two general categories: prototype testing and flight-unit testing. In addition to the established Vanguard test specifications, numerous other component and assembly tests were performed. For example, the prototype unit was given a centrifuge and vibration test of 8- to 30-g acceleration, combined with 8-g sinusoidal vibration from 20 to 100 cycles per second (the limit of the equipment immediately available). Special tests insuring the reliability of the caterpillar motors consisted of numerous vacuum firings, sample batch firings, and selection of reliable caterpillar motors by means of resistance checks: if the internal resistance was over 7 ohms, reliability decreased and, probably, the unit was not properly sealed. A test for battery reliability was also devised. By measuring the open-circuit voltage, applying a 50-milliampere load and recording the voltages at 30 seconds and 1 minute (then removing the load), it was found that the voltage of an acceptable flight battery should increase slightly from the 30-second to the 1-minute check points.

All separation mechanisms were checked for proper operation on a programed centrifuge. The facilities of the Diamond Ordnance Fuze Laboratories in Washington, D. C. were employed. The test may be described briefly: A typical third-stage acceleration-time curve is cut on dark film. The film is placed on a video-type tube and a pin point of light is focused on the screen (from within the tube). This light beam follows the acceleration-time curve, and the associated electronics cause the centrifuge to follow the programed acceleration. Sweep time and g limits are preset in the equipment, and the desired program is followed. The monitoring mechanism for this test is a small 360° potentiometer connected to the timer; timer functions are transmitted through slip rings recorded on a Sanborn recorder. Simultaneously an accelerometer, located at the mechanism, gives the acceleration level and this information is also recorded on the same Sanborn tape. The resultant recording indicates the arming g-level, actuation g-level, and time functions of the mechanism.

In order to study the actual separation, a Fastax camera was used to photograph the sequence (Figure 6). The sphere was attached to a thin spring-steel ribbon, placed on low-friction rollers and attached to a counterweight to counteract both friction and satellite mass. The caterpillar motors were fired by current from an external battery and the camera recorded the separation sequence.

The resulting separation velocity was obtained by experimentally determining the kinetic energy in the three small leaf springs installed on the separation sleeves. Several sleeves were used to determine the average separation velocity of approximately one foot per second. The actual velocity was not critical.

All separation mechanisms were dynamically balanced prior to flight; the degree of balance attained was approximately 0.1 inch-ounce. The balancing equipment was the same as that used on other Vanguard satellites.

D-495

CONCLUSIONS

The Vanguard I satellite (1958 Beta) survived the flight environmental conditions and has survived the orbital environmental conditions for over two years. Separation from the third-stage rocket was accomplished at the prescribed time. Therefore, the structural and mechanical design of the Vanguard I satellite and separation mechanism proved adequate.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Raymond Engineering Laboratory, Middletown, Connecticut, which produced and modified the separation mechanisms; to the Diamond Ordnance Fuze Laboratory, Washington, D.C., for providing the programed centrifuge for testing and calibrating the separation mechanisms; to the Naval Research Laboratory for shop facilities and services and testing facilities and services; to the Vanguard staff, particularly Mr. J. E. Bush, Jr. J. C. MacFarlane, Mr. F. T. Martin, LTJG A. Simkovich, Mr. R. Gottleib, and many others, for their untiring efforts in the design, development, testing and checkout of the Vanguard I satellite and separation mechanism.

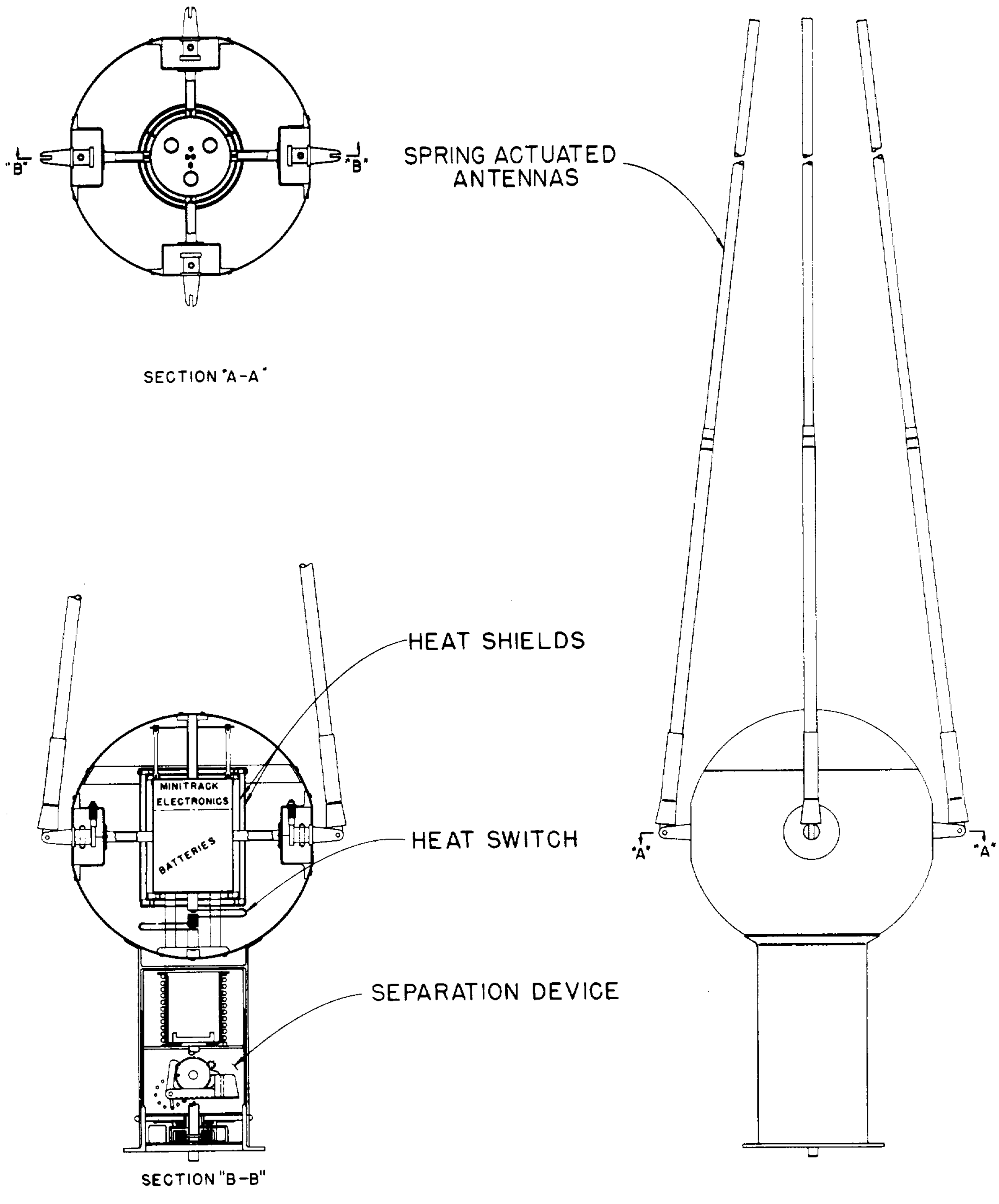


Figure 1 - Vanguard minimal (test-vehicle) satellite before modification

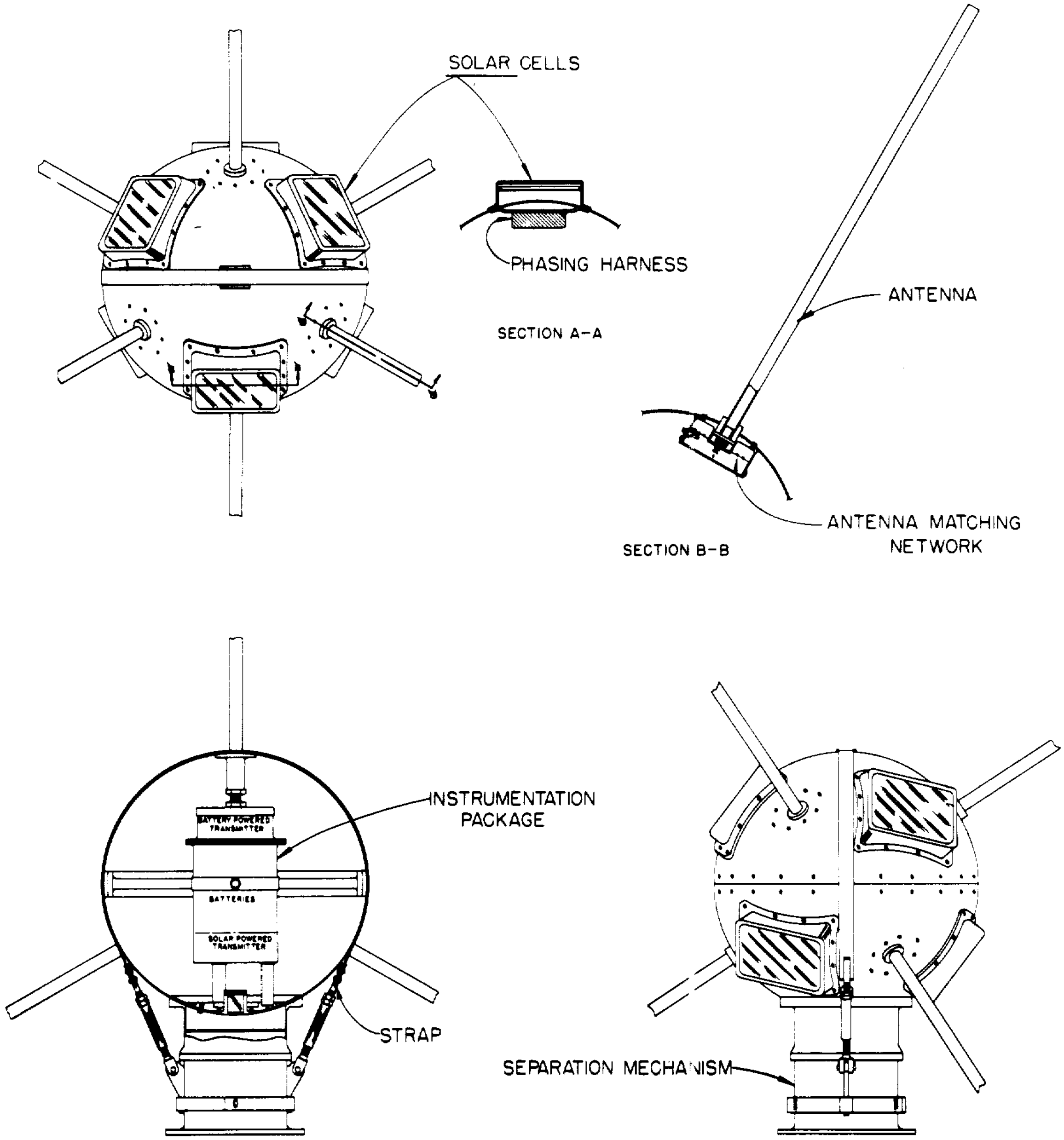


Figure 2 - Vanguard test-vehicle sphere, after modification

D-495

D-495

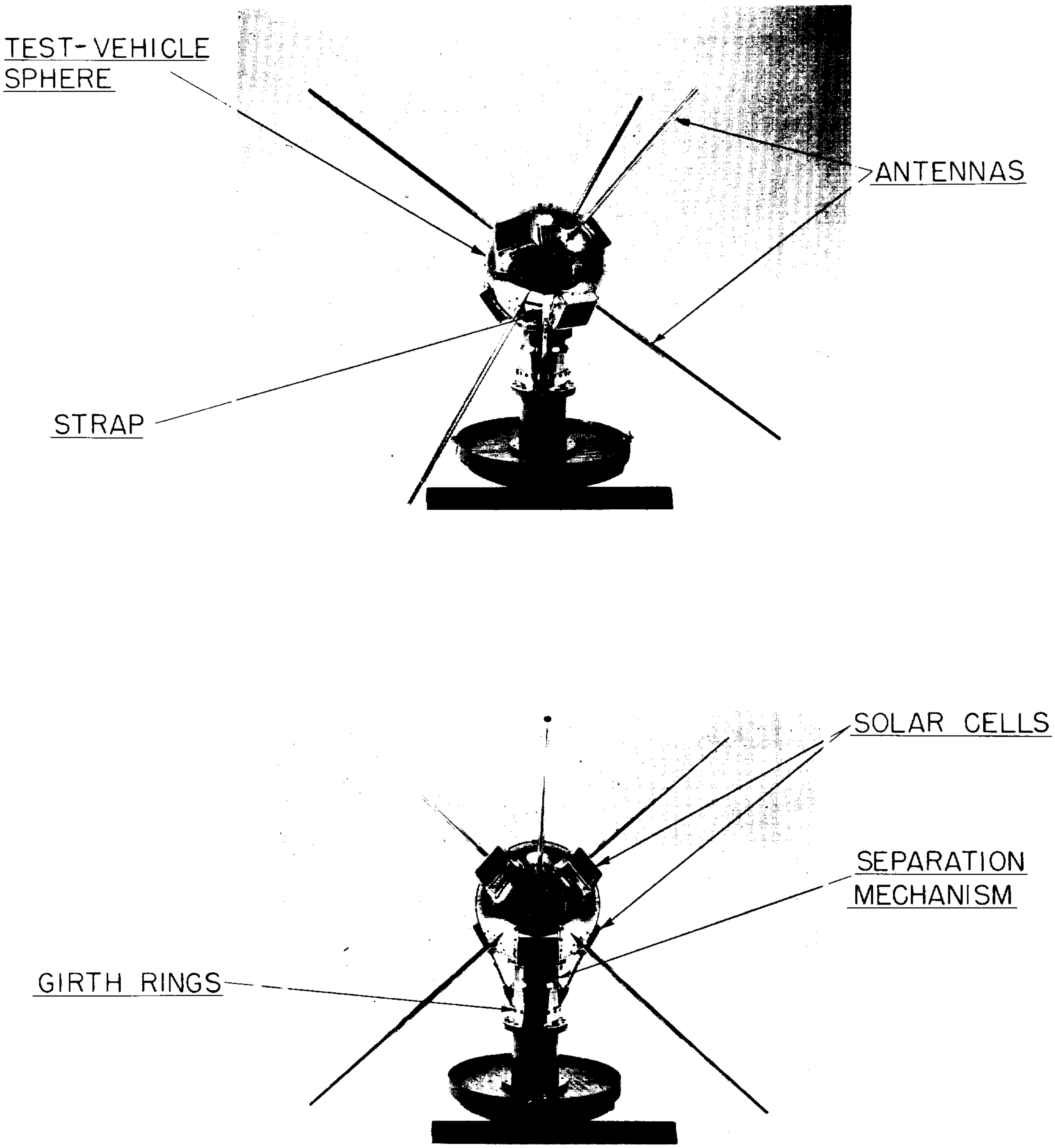
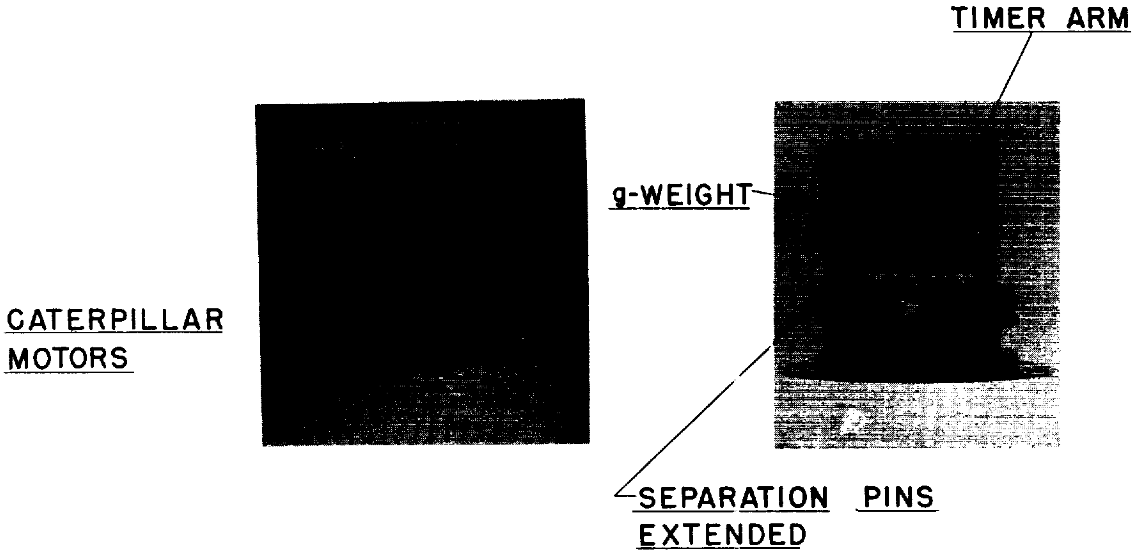
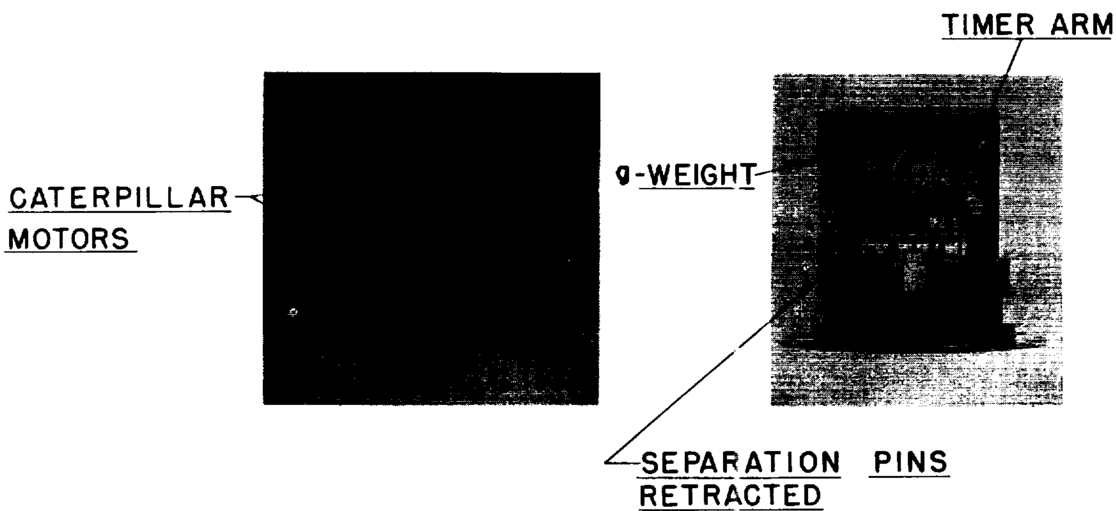


Figure 3 - Test-vehicle sphere mounted on separation mechanism



(a) Unfired position



(b) Fired position

Figure 4 - Separation mechanism in unfired and fired position

D-495

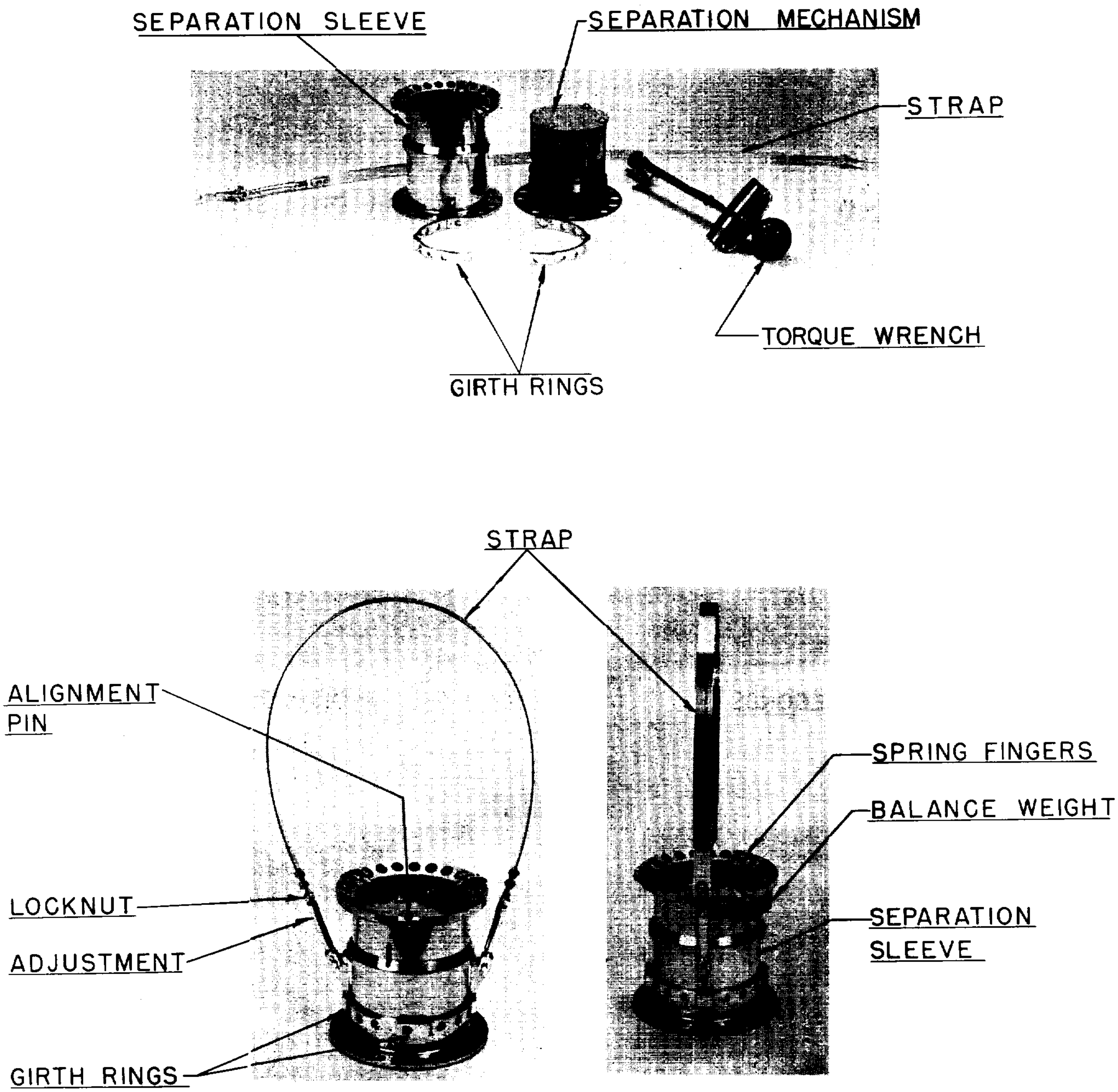


Figure 5 - Test-vehicle sphere separation device

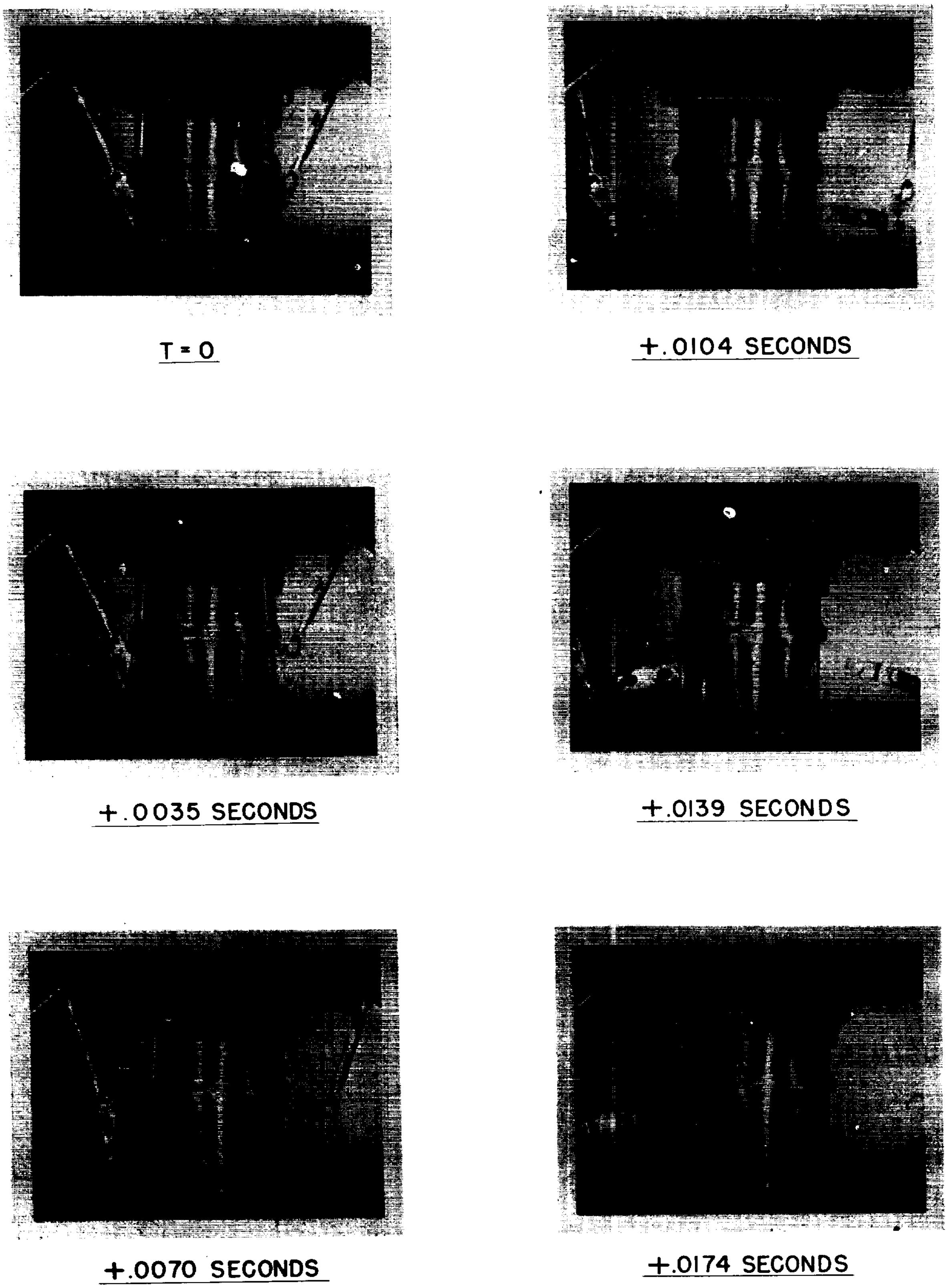


Figure 6 - Test-vehicle sphere separation

D-495

D-495

Appendix A

Vanguard I Satellite Weight Summary

Component	Weight (lb)
Shell - north	0.189
Shell - south-ring-doubler-bushings	0.325
Main support can	0.066
Battery can	0.063
Battery cover	0.017
Can - solar-power	0.018
Cover - solar-power	0.012
Cover - battery-power can	0.013
Anteanna cup (6)	0.185
Antenna-cup cover (6)	0.040
Antenna pin (6)	0.002
Antenna tube (6)	0.139
Teflon insert (6)	0.061
Plug (6)	0.009
Terminal (6)	0.005
Cap (6)	0.001
Electronics insert (6)	0.189
Crystal holder	0.013
Crystal clamp	0.002
Base support	0.045
Bottom Kel-F supports (3)	0.013
Side Kel-F supports (4)	0.020
Top Kel-F support	0.015
Spacer Kel-F	0.004
Strap guides	0.002
Screws	0.051
Wire clips	0.002
Wire wrapping	0.004
Solar cells	0.557
Phasing harness and boards	0.198
Transmitter - battery powered	0.059
Transmitter - solar powered	0.065
Batteries	0.670
Crystal	0.002
Turnon plug potting	0.044
Balance weights	0.036
Added wiring, etc.	0.011
Computed weight of ball	3.147
Actual flight weight	3.211
Difference	.064

Percent difference $\frac{0.064 \times 100}{3.211} = 2\%$

Actual weight	3.211
Separation mechanism	0.830
Total weight	4.041