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THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)/ GODDARD SPACE FLIGHT CENTER (GSFC) SOUNDING-ROCKET PROGRAM

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June 1976

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FOREWORD

This document has been prepared to serve as an overall introduction to the NASA Sounding-rocket Program as managed by the Goddard Space Flight Center (GSFC). It provides a description of the various sounding rockets, auxiliary systems (telemetry, guidance, and so on), launch sites, and services which NASA can provide.

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1. INTRODUCTION

The use of sounding rockets for space research was begun about 1946. In the 30 years since these first efforts, many rockets have been employed to probe the upper air and space, with a multitude of scientific instruments. These have resulted in or contributed to many discoveries of major scientific and practical significance.

Basically, sounding rockets are vehicles which carry scientific instruments in nearly vertical trajectories to altitudes above 40 km (25 mi). They may have one or more stages and use liquid or solid propellants. Most sounding rockets are fin-stabilized. During powered flight, they weathercock into the wind. However, a few of the newer types, such as the Aries, use a simple guidance system (actually a heading system) with moveable nozzles.

In 1961, the average payload for sounding rockets was 23 kg (50 lb) and the altitude achieved was less than 160 km (100 mi). This past year the average payload weight was approximately 160 kg (350 lb) and the altitudes were up to 1000 km (621 mi). The experiments and instrumentation have also become more sophisticated; for example, pointing accuracies of about 1 arc-min at several targets per mission are now achieved for stellar astronomy. Accuracies of approximately 15 arc-min are available for x-ray sources and other non-trackable targets.

Sounding-rocket research has become an important cornerstone of the National Aeronautics and Space Administration (NASA) International Cooperative Programs. NASA provides research sounding-rocket flight opportunities for scientists and agencies of other countries. During the past 15 years, 20 countries have joined NASA in cooperative projects resulting in the launching of more than 600 rockets from ranges outside the United States.

The NASA sounding rockets are all identifiable by the numbering system used at NASA/GSFC which is shown in Table 1 and used in this document. The number denotes the type of rocket. The letters which follow signify the agency conducting the experiment and the field of science being investigated. For example, NASA 26.013 GT denotes an Aerobee-200 rocket being flown for GSFC to accomplish Test and Support.

Table 1

NASA Sounding-rocket Numbering System

Number	Project	Number	Project	First Letter	Description	Second Letter	Description
1	Aerobee-100	17	Aerobee-350	A	Government agency other than NASA	A	Aeronomy
2	Arcon	18	Nike-Tomahawk				
				C	Industrial corporation	B	Biology
3	Nike ASP	19	Black Brant IV				
				D	DOD	C	Cometary physics
4	Aerobee-150, -150A	20	Bull Pup Cajun				
				G	GSFC	E/I	Plasma physics
5	IRIS	21	Black Brant VC				
				I	International	G	Galactic astronomy
6	Aerobee-300	22	Black Brant III B				
				N	Other NASA Centers	H	High-energy astrophysics
7	Argo E-5	23	Astrobee-D				
8	Javelin	24	Aries	U	University	L	Lunar and planetary astronomy
9	Skylark	25	Astrobee-F				
10	Nike-Cajun	26	Aerobee-200, -200A	W	WFC	M	Meteorology
11	Argo D-8	27	Nike-Black Brant V			P	Special Projects
12	Special Projects	28	Nike-Malemute (500 km)			R	Radio Astronomy
						S	Solar physics
13	Aerobee-170, -170A	29	Terrier-Malemute (700 km)			T	Test and Support
14	Nike-Apache	30	Hawk				
15	Arcas (Boosted I, II; super)	31	Nike-Hawk				
16	Astrobee-1500	32	Nike-Javelin				

2. UNIQUE CAPABILITIES

The sounding rocket has a unique and useful place in space research. Some of its capabilities include:

- Providing the only means of obtaining direct measurements in the 40- to 200-km (25- to 125-mi) altitude range,
- Experiment sizing, qualification, and calibration,
- Quick payload recovery,
- Logistic flexibility,

- Short lead-time and low cost, and
- Applicability to graduate school research.

3. PAST ACCOMPLISHMENTS

Sounding rockets provided the first direct examination of that portion of the electromagnetic spectrum with wavelengths shorter than 3000 Å. Up to that time, measurements had been restricted by the opaque nature of the Earth's atmosphere. Observations of the solar ultraviolet spectrum by a spectrograph were made in 1946. One of the earliest discoveries of rocket solar astronomy was the discovery of solar x-rays originating in the million-degree corona.

Over the years, knowledge of the solar spectrum has steadily increased as the observable limit has been extended from approximately 2200 Å in the early measurements, through the line-emission region, and into x-ray wavelengths. By 1950, the solar spectrum had been broadly mapped and the outlines of the mechanisms by which solar-ionizing radiations produce and control the ionosphere were discernible. In recent years, satellites, too, have monitored the various emission levels; but the principal characteristics of the emissions, so important to our understanding of the Sun, the stars, and the upper atmosphere, were identified from rocket data.

Experience shows that sounding-rocket research contributes directly to the more sophisticated research conducted by satellites. In virtually every case, early developmental models of research instruments, intended for flight on satellites, are tested on sounding rockets. These flights not only provide first-rate scientific data, but also show how the instruments can be redesigned to be more reliable and provide even more useful data than was originally envisioned. In addition, sounding rockets have been employed to carry instruments by which satellite experiments have been calibrated. Without such periodic recalibrations, most of the value of relatively long-lived satellite experiments would be negated or diminished as the orbiting instruments' characteristics changed with time, in an unknown manner.

In addition, to the basic research activities by the NASA Headquarters Office of Space Science (OSS) in the fields of solar physics, galactic astronomy, magnetospheric physics, aeronomy, lunar and planetary atmospheres, and high-energy astrophysics, at least three more direct applications have been made:

1. The Skylab calibration rocket series,
2. Space processing (application-oriented studies), and
3. Investigation of short-lived phenomena.

3.1 SKYLAB CALIBRATION ROCKET SERIES

The Skylab calibration rocket series consisted of six calibration launches of a new Black Brant VC payload configuration for the Naval Research Laboratory (NRL) and the Harvard College Observatory (HCO). The need for calibration was made known to GSFC/Sounding-rocket Division (SRD) in June 1971, and the directive to proceed was furnished in early 1972. The division successfully launched its first calibration rocket on June 13, 1973 for NRL.

Five of the six actual calibration rockets were successful. Three successful flights calibrated SO-82 (Apollo Telescope Mount (ATM) telescope aboard Skylab provided by NRL) and two successful flights calibrated SO-55 (ATM telescope aboard Skylab provided by HCO). These latter two ATM telescopes were calibrated because experiment degradation had occurred during the 2.5 years between the fabrication and launch of Skylab. NRL and HCO both observed that the efficiency of the optics as well as the electronics had decreased. These phenomena were documented by HCO. In addition to optic and electronic changes, the film being used by NRL to record the solar data degraded from exposure to the space environment, began fogging from age, and generally lost sensitivity due to temperature/humidity excursions during long periods of storage.

These rocket data were used to develop calibration criteria which scientists used in the interpretation of data from ATM experiments SO-82A, SO-82B, and SO-55A. Note that the rocket data were taken nearly simultaneously and on the same solar target with the data obtained by the respective ATM telescopes aboard Skylab.

3.2 SPACE PROCESSING

A second series of rockets was used to conduct application-oriented experiments to advance materials technology. These rockets are better known as the NASA Space Processing Application Rockets (SPAR). The first space-processing experiment was successfully launched on December 11, 1975. At least 14 more investigative flights are now planned. This program encourages experimentation which promises new technology; better materials; or new methods for producing consumer products more easily, more cheaply, and better than present methods.

The first launch of the space-processing experiments provided information, which could not be explained or predicted theoretically, on advanced materials concepts relating to how metallurgical recombining, refining, and so on take place under zero "G" conditions. It is anticipated that many quality products can be developed in this new space environment and that this will be the start of another industrial concept.

3.3 SHORT-LIVED PHENOMENA

The third program which used rockets was the January 1974 investigations of Comet Kohoutek. These investigations used rockets, satellites, and ground-based instruments. In many instances, these data sources were coordinated to enhance final interpretation of this quick-reaction program.

The most recent investigations were of Comet West which also made use of sounding rockets.

3.4 OTHER CONTRIBUTIONS

Other achievements of sounding-rocket research which have been noted by the Space Science Board of the National Academy of Sciences are:

- The development of three new branches of astronomy—ultraviolet, x-ray, and gamma-ray;
- Characterization of the main features of the Earth's upper atmosphere;
- First recognition and definition of geocorona;
- Expanded knowledge of ionospheric chemistry;
- Detection of the existence of electrical currents in the ionosphere and electrojets;
- Accurate descriptions of particle fluxes in auroras;
- Significant influence in space astronomy results.

4. DISCIPLINES UNDER INVESTIGATION

The NASA/GSFC Sounding-rocket Program, used principally in the fields of solar physics, galactic astronomy, magnetospheric physics, aeronomy, lunar and planetary atmospheres, and high-energy astrophysics, presently includes sounding rockets to:

- Map the parameters of the Earth's atmosphere between 40 and 200 km (25 and 125 mi);
- Study pressure, temperature, and density of the ionosphere;

- Measure ionospheric electric currents; and

- Study auroras and airglow.

Stellar ultraviolet (UV) and optical spectra, as well as radiation from x-ray sources, are observed. The interrelation of these parameters and their dependence on solar heating, solar flares, geomagnetic storms, trapped radiation fluctuations, and meteor streams have been investigated with sounding rockets to supplement the knowledge obtained from aircraft, balloons, satellites, and ground-based observations.

Special situations also occur where simultaneous vertical measurements are required at several locations, or where data from vertical cross sections are required to supplement data from horizontal cross sections of the Earth's atmosphere.

The development of attitude stabilization systems makes the Sounding-rocket Program uniquely suited for exploratory astronomical observations in the x-ray, UV, and radio regions of the electromagnetic spectrum which are not visible from the Earth's surface.

Another important new field in x-ray astronomy being investigated with sounding rockets is the study of low-energy x-rays (<500 eV) which are absorbed by the very tenuous material between stars.

5. VEHICLES

A family of sounding-rocket vehicles has been developed by NASA over the years to meet experimenter requirements in sounding-rocket missions. This family of vehicles provides experimenters the capability of economically placing 23- to 1360-kg (50- to 3000-lb) payloads at altitudes up to 1000 km (621 mi). When necessary, provisions can be made for payload recovery or highly accurate payload pointing.

Configuration drawings of the basic family of NASA sounding-rocket vehicles are shown in Figure 1, while Figure 2 shows their performance capabilities. Table 2 provides general data on each of the NASA sounding-rocket vehicles. Figure 3 is a photograph of a typical horizontal check with the Vertical Assembly Building doors open to expose payload to radar radiation field. Figure 4 is a photograph of a typical White Sands Missile Range (WSMR) launch showing the launch tower.

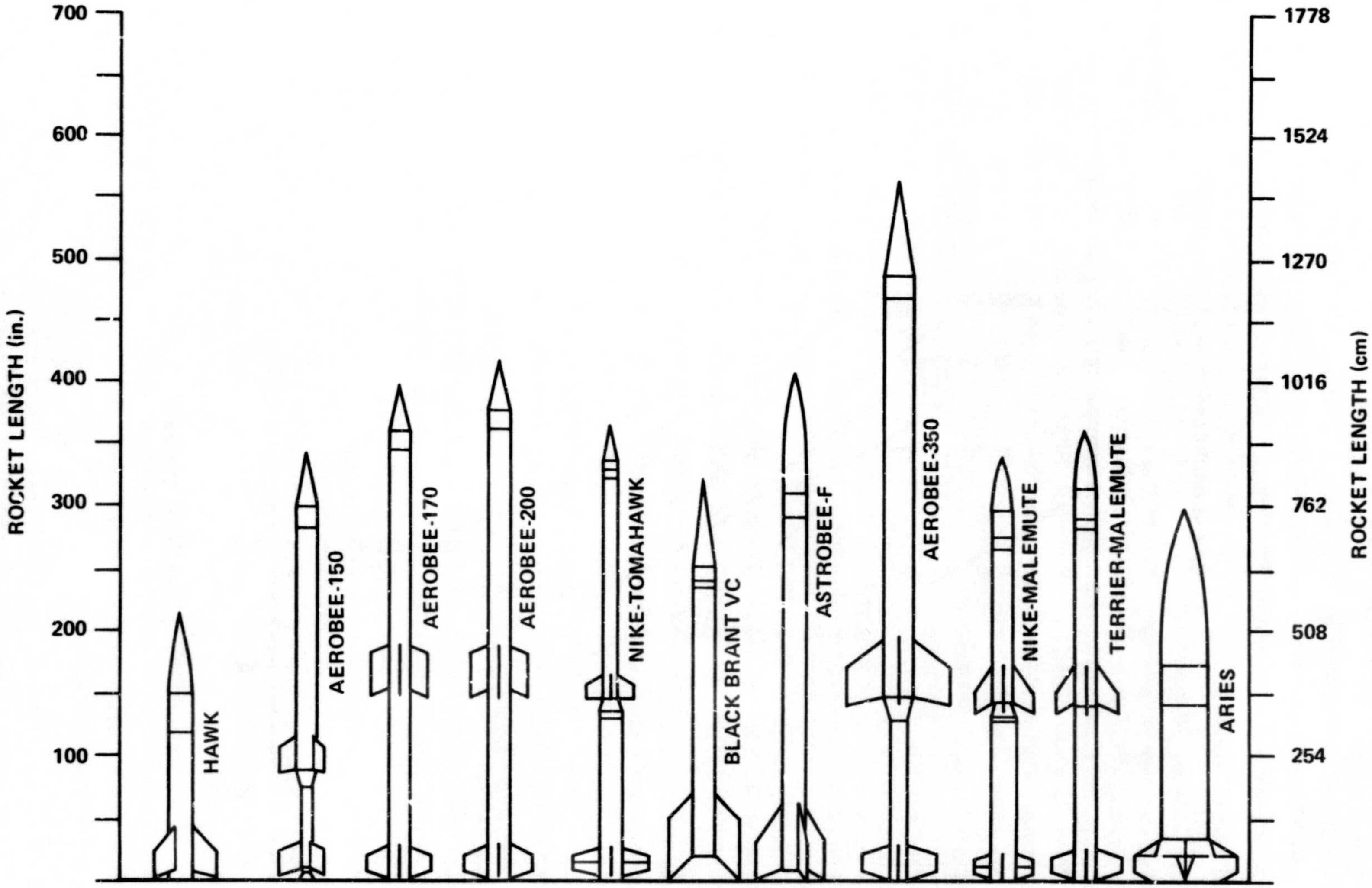

Figure 1. Basic Family of NASA Sounding-rocket Vehicles

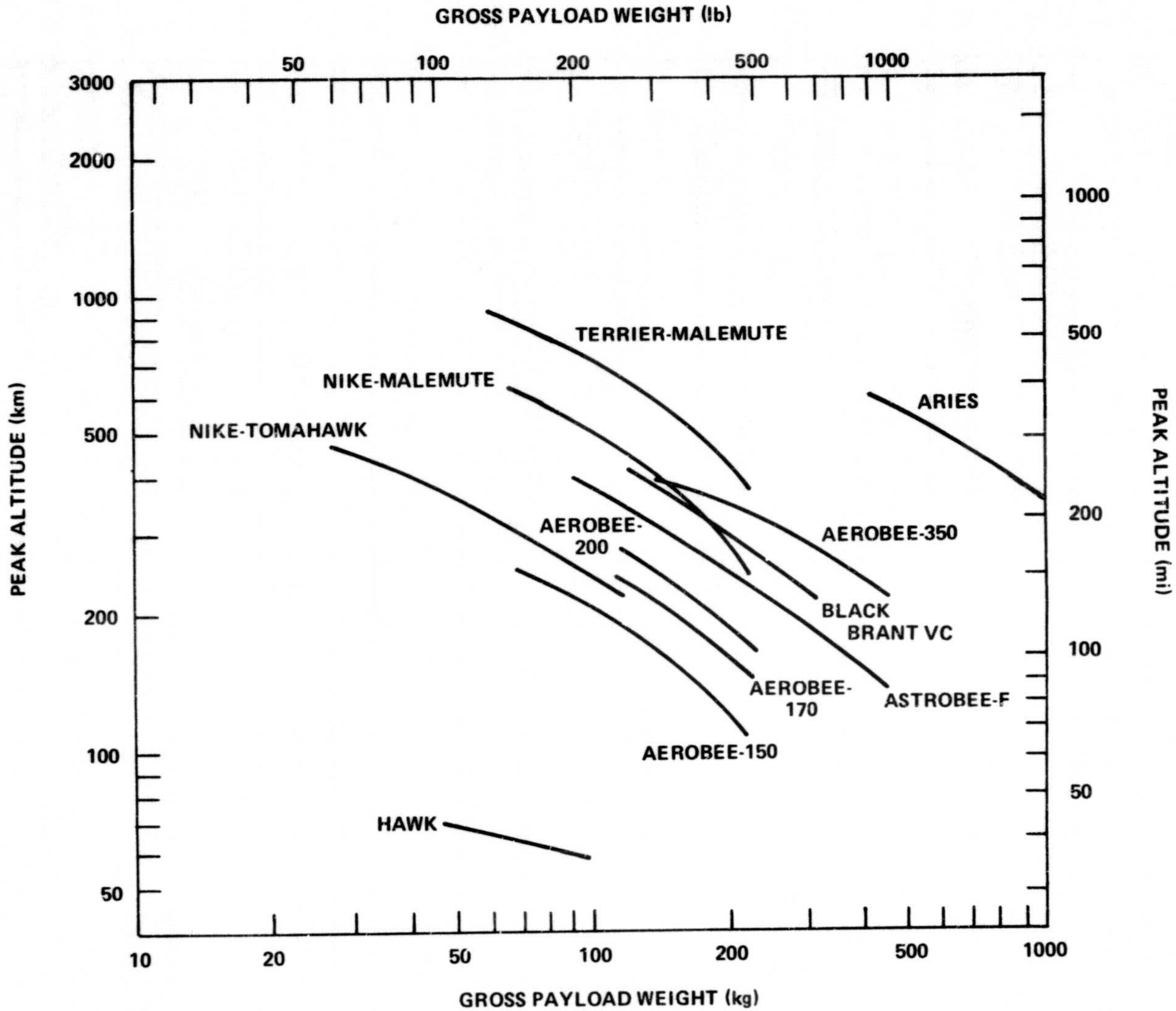

Figure 2. Performance Capabilities of NASA Sounding-rocket Vehicles

Table 2

NASA Sounding-rocket Vehicle Data

Rocket Vehicle	Nominal Payload Diameter [cm (in.)]	Payload Weights [kg (lb)]		Subsystem Availability		Launch Range Compatibility		
		Light	Heavy	ACS	Payload Recovery	WSMR	WFC†	Other
Hawk	35.6 (14)	45 (100)	91 (200)	–	X	X	X	X
Aerobee-150	38.1 (15)	68 (150)	227 (500)	X	X	X	X	X
Aerobee-170	38.1 (15)	113 (250)	227 (500)	X	X	X	X	X
Aerobee-200	38.1 (15)	113 (250)	227 (500)	X	X	X	X	X
Nike-Tomahawk	22.9 (9)	27 (60)	118 (260)	X	X	X	X	X
Black Brant VC	43.7 (17.2)	136 (300)	408 (900)	X	X	X	X	X
Astrobee-F	38.1 (15)	91 (200)	408 (900)	X	X	X	X	X
Aerobee-350	55.9 (22)	136 (300)	454 (1000)	X	X	X	X	–
Nike-Malemute	40.6 (16)	68 (150)	227 (500)	*	*	*	X	X
Terrier-Malemute	40.6 (16)	68 (150)	227 (500)	*	*	*	X	X
Aries	111.8 (44)	454 (1000)	1361 (3000)	X	X	X	X	X

*Operation of Nike-Malemute and Terrier-Malemute at White Sands Missile Range (WSMR), New Mexico with heavier payloads (including Attitude Control System (ACS) and recovery) is under consideration.

†Wallops Flight Center, Virginia.

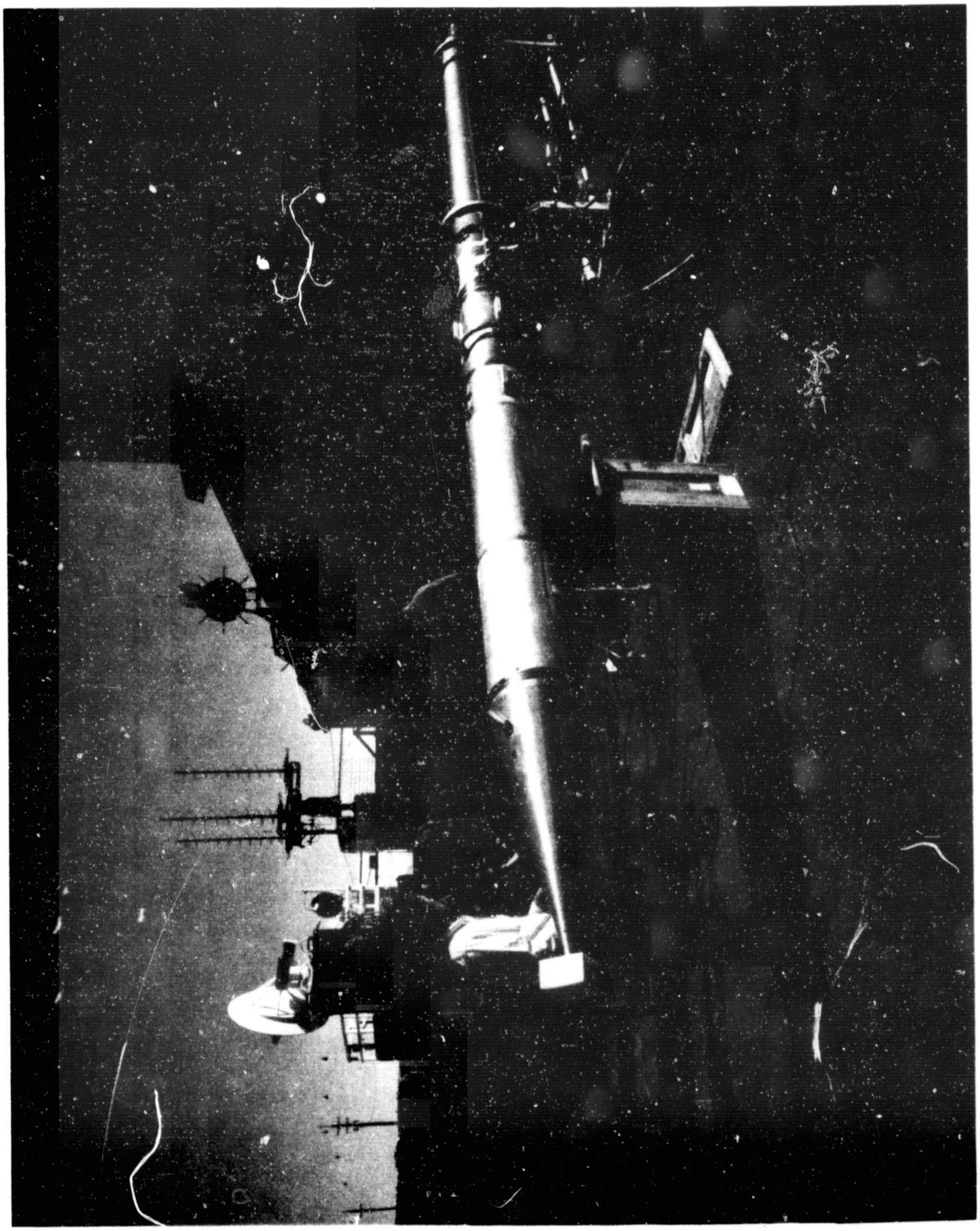

Figure 3. Aerobee Rocket NASA 26.021 UG Horizontal Check, January 14, 1974

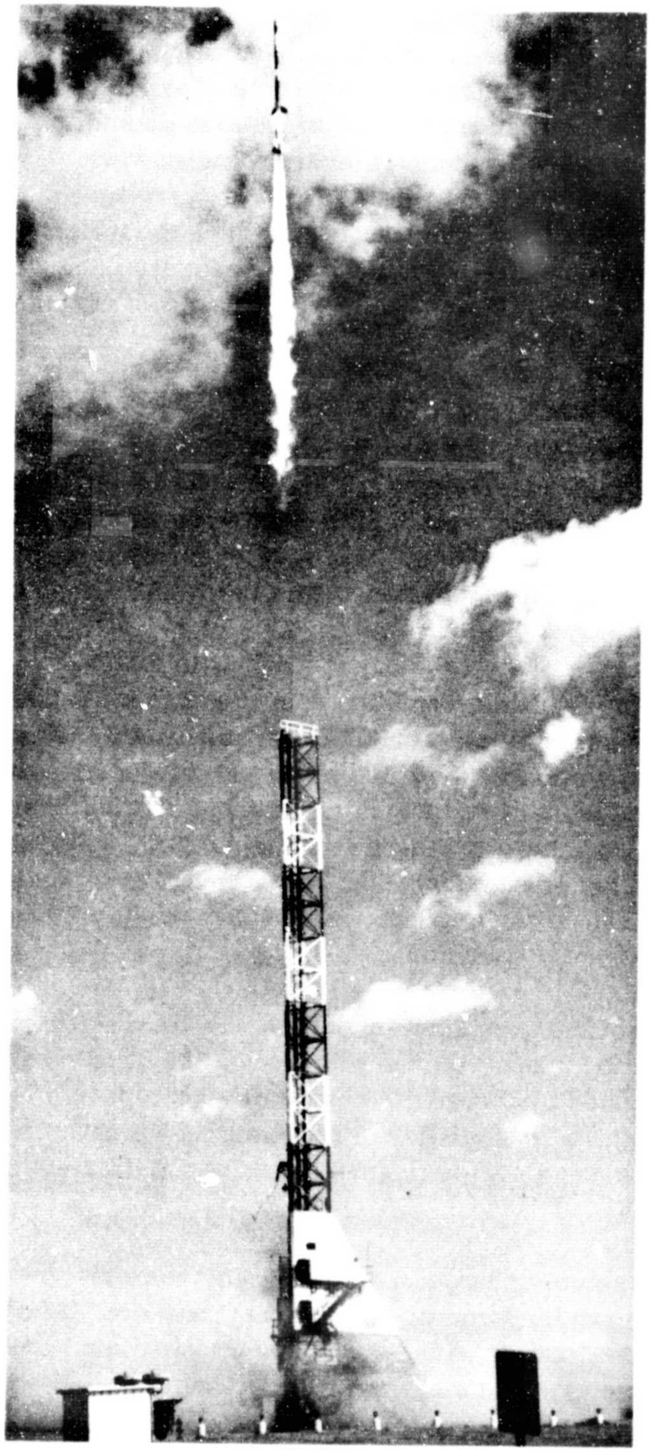

Figure 4. Launch of Aerobee-200 Rocket NASA 26.013 GT from White Sands Missile Range (WSMR), New Mexico, November 20, 1972.

The performance capabilities shown in Figure 2 result from an 85° QE sea-level launch as a function of gross payload weight, except for the the Aries vehicle. (Aries is launched vertical with a pitch program which allows for a given impact point.) Deviations from the performance capabilities given in Figure 2 would result from changes in payload geometry, protrusions such as antennas, or variation in launch elevation angle.

Gross payload weight includes, as necessary, the weight of the nosecone, any cylindrical extensions, telemetry, ACS, recovery package, and, of course, the experiment itself. Examples of the breakdown of typical payload weights are given in Figure 5.

For many experiments, the time available above a specific altitude is of particular importance. Figure 6 provides data on the experiment time available above specified altitudes versus apogee of the rocket. This time—referred to as time above altitude—varies widely with payload weight and elevation angle. Although complete data are not provided, Figure 2 does give some idea of the wide range of capability available within the NASA/GSFC family of sounding-rocket vehicles.

A desirable feature of the Sounding-rocket Program is the capability to launch rockets from remote locations. This capability is largely dependent on mobility of the launcher systems. With the exception of the Aries vehicle which contains a guidance system and which is launched from a base-supported stand, three types of launchers are used for NASA/GSFC sounding rockets: the zero-length launcher, rail launcher, and tower launcher. The first two are easily transported. The tower launcher is used for the higher performance vehicles to minimize impact dispersions.

The sounding rockets are spun to reduce vehicle dispersion and to maintain gyroscopic stability after the vehicle leaves the atmosphere. The spin rate is strongly influenced by the vehicle dynamics and spin-up is induced aerodynamically by canting the fins. Where experimental requirements dictate a lower spin rate the package can be despun to the desired rate after the payload leaves the atmosphere.

The payload diameter (Table 2) indicates the nominal payload size. Bulbous payloads are flown on some of the sounding rockets. The Astrobee-F flies with payloads ranging up to 56-cm (22.1-in.) in diameter. These larger payloads, of course, reduce the apogee accordingly.

Thermal environment is an important consideration in the design of a sounding-rocket system for a specific mission. This is especially true in the higher

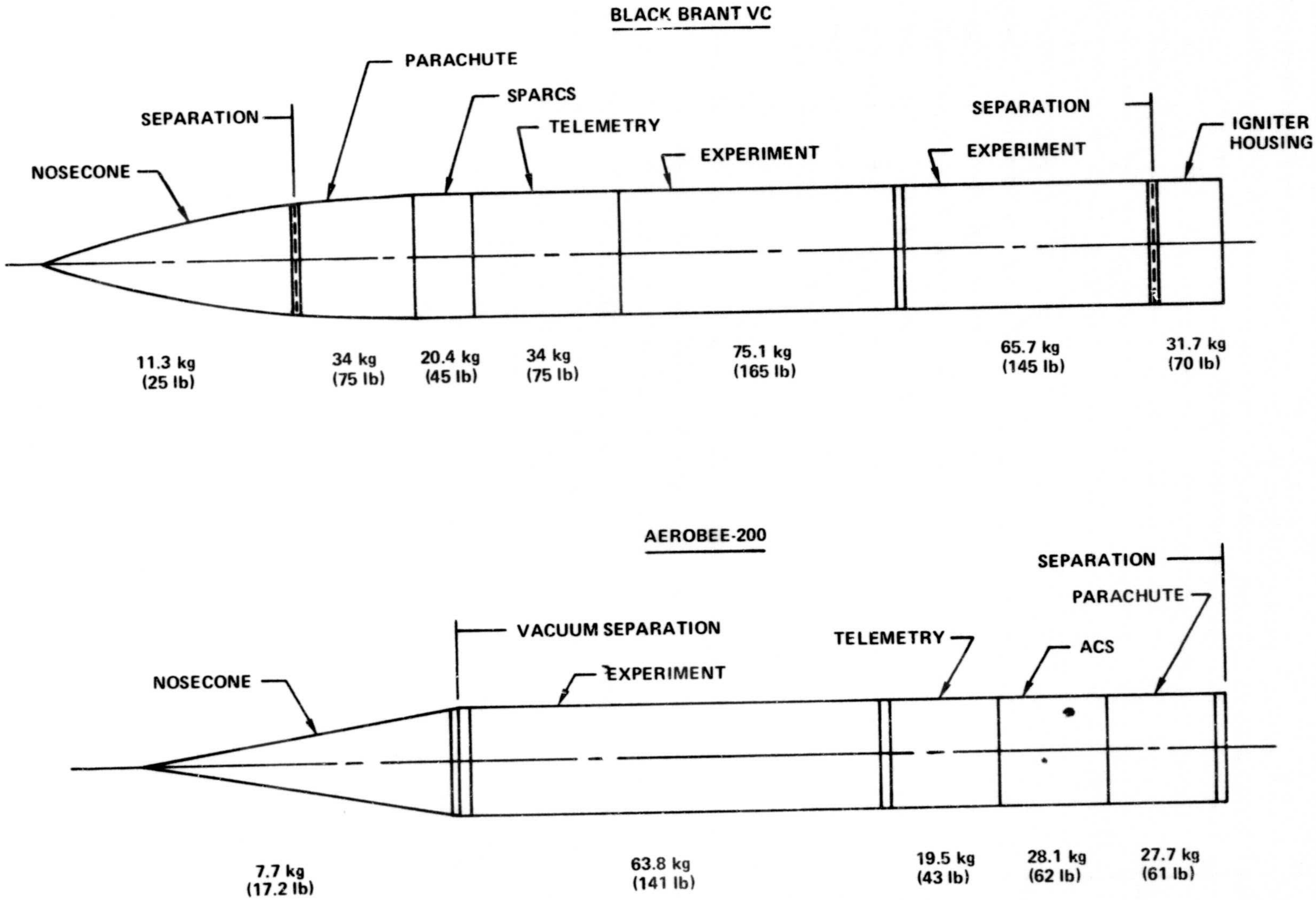

Figure 5. Typical Sounding-rocket Payload Systems

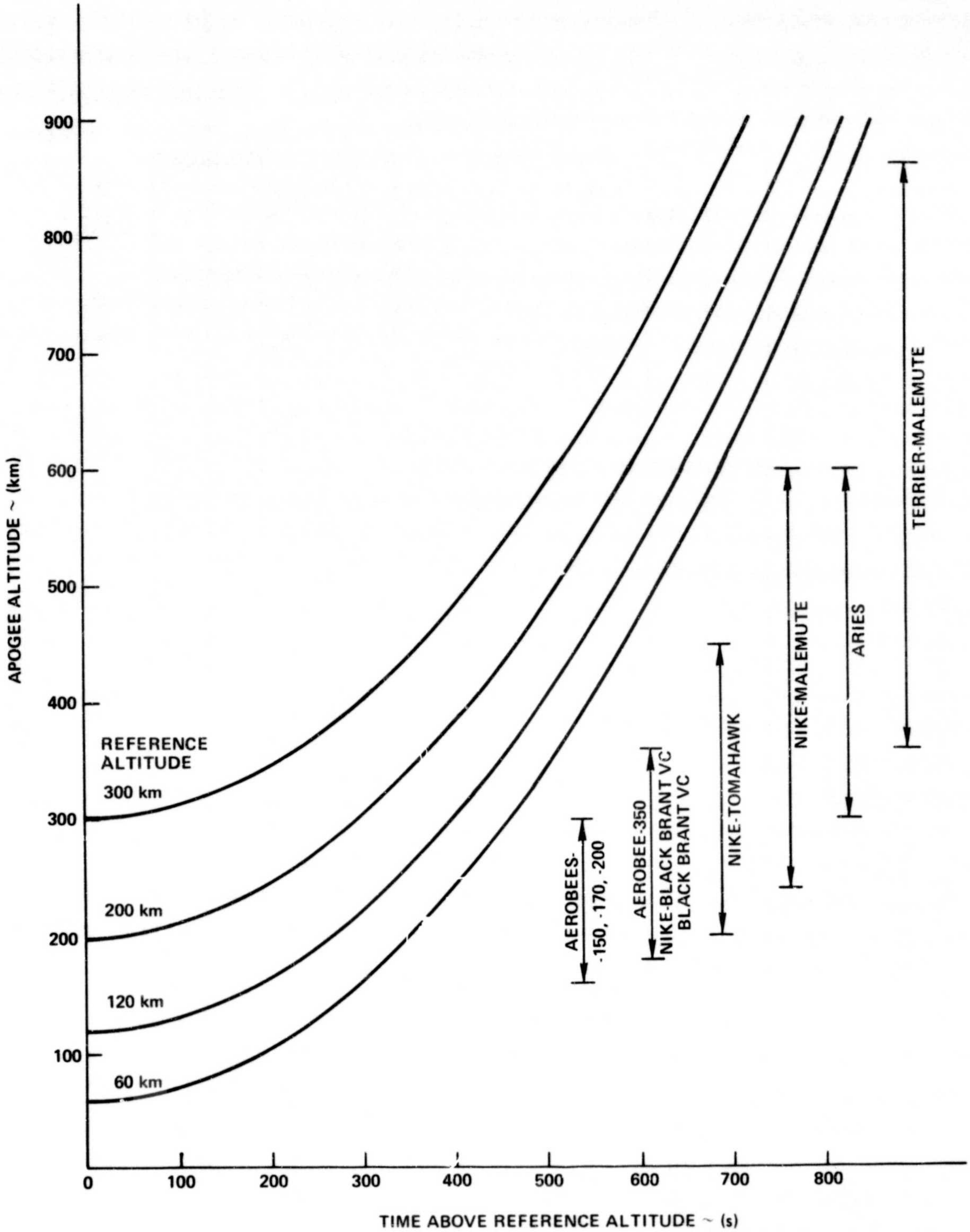

Figure 6. Experiment Time Above Specified Altitudes Versus Apogee of Rocket

performance vehicles where the effects of aerodynamic heating can be critical to either the instrumentation or the structural integrity of the vehicle itself.

Thermal protection can be developed easily, when required. Fortunately, the effect of the additional weight of thermal protection systems on vehicle performance is usually negligible; however, the potential of outgassing on the instruments must be evaluated.

In order to meet increasingly stringent requirements of sounding-rocket experimenters, NASA is developing three new types of sounding rockets: the Aries, the Nike-Malemute, and the Terrier-Malemute. The Aries sounding rocket, the second stage of the Minuteman launch missile obtained as surplus from the U.S. Air Force (USAF), will enable NASA to carry larger and heavier payloads than in the past. For example, earlier sounding-rocket payloads could not be larger than 53.5-cm (21-in.) in diameter. The Aries will increase the diameter to 112 cm (44 in.), permitting a four-fold increase in light-gathering power for a telescope and thus the ability to see objects four times dimmer. Continuing efforts will include the development of a payload recovery system. Payload proposals have been accepted and a cooperative program with West Germany is being conducted. This vehicle capability is ultimately expected to help develop payloads to fly on the Space Shuttle.

The two versions of the Malemute sounding rocket—the Nike-Malemute and the Terrier-Malemute—are designed to place payloads at altitudes of 500 km (311 mi) and 700 km (435 mi). These regions, almost totally unexplored to date, are the sites of very important magnetospheric physics phenomena.

NASA's Sounding-rocket Program also contributes to the Space Shuttle Program by providing a ready means for flight testing equipment ultimately scheduled for use aboard the Space Shuttle. The unique contribution of sounding rockets is that instrument development can begin early and proceed in an evenly paced fashion to coincide with the Space Shuttle launch schedule. Such an orderly development will be less costly and will allow the inevitable "bugs" to be worked out, thus increasing instrument reliability. After the Space Shuttle is operating, sounding rockets will continue to contribute by providing calibration data and special flights designed to obtain particular correlating data.

6. ATTITUDE CONTROL

One of the most noteworthy aspects of the Sounding-rocket Program was the advent of the pointed and stabilized sounding rocket and/or sounding-rocket payload. It has transformed sounding rockets into stabilized, oriented satellites capable of conducting sophisticated scientific experiments, unencumbered by the major effects of the Earth's atmosphere, gravity, or environment during the coasting or free-fall portions of the rocket trajectory. Many observations, impossible from the ground, do not require satellites in orbit. With sounding rockets, these measurements can be performed during a few minutes exposure above the atmosphere. Thus, the pointed and stabilized Sounding-rocket Program is an economical and scientifically effective tool which complements and augments its scientific satellite programs. The major disadvantage, limited experimental time, can actually be one of its major advantages, allowing simple, rapid, and inexpensive recovery of the payload. Rapid laboratory recalibration of the instruments and the use of photographic techniques for experimentation and attitude verification are relatively simple matters with the rocket payload. The reuse of the scientific instruments, control systems, and support instrumentation on future flights adds significantly to the cost effectiveness of what is already a relatively inexpensive "ride-in-space."

Pointed and stabilized sounding rockets have been, and are still being, used to cross reference or calibrate an orbiting observatory ATM by flying a pointed payload using instruments which are the same as or similar to those in the observatory itself. Table 3 lists the more frequently used ACS's and briefly defines their characteristics and estimated performances.

Little or no attempt has been made to control the sounding rocket or payload during the boost phase of flight. This is due primarily to the desire to keep the vehicle and control system cost, complexity, and weight at a minimum. As noted previously, some development effort is currently underway to provide a boost control guidance system for medium-sized sounding rockets; however, all of the control systems listed in Table 3 initiate control after the rocket or payload is essentially free of aerodynamic effects. In the case of the gyro-referenced systems, a reference is maintained or "remembered" from the ground up, and, upon initiation of control, the vehicle or payload is aligned to the gyro reference. Fine guidance optical error sensors are used either to update or replace the gyro reference to effect greater accuracy and/or stability. Rate-integrating gyros can be used to provide low drift, high accuracy pointing at non-trackable targets. In the case of the strictly solar-pointing systems, the general practice is to use coarse solar sensors as the reference to drive the payload into the acquisition field-of-view of the fine solar sensor. If a magnetometer is used to control the third axis, then no displacement gyroscopes are required.

All of the control systems that are now in operation use cold-gas reaction jets to control and stabilize the vehicle. Most operate in an on/off or "bang-bang" mode, but some solar-pointing systems now use a fluidic proportional cold-gas thruster. Most "bang-bang" systems vary the duration and frequency of the

Table 3

Characteristics of Sounding-rocket Attitude Control Systems (ACS)

Control System	Cognizant Agency (Manufacturer)	Operational Mode	Rocket Availability	Fine Guidance Error Sensor (FGES)	Approx. Length and Weight (Exclusive of FGES)	Expected Pointing Accuracy	Limit Cycle Noise and Frequency (Typical)	Notes
1. STRAP-III	NASA-GSFC (Ball Bros. Res. Corp. (BBRC))	Three-axis, gyro referenced, cold-gas jet controlled, inertially programmed system with capability for fine pointing and stabilization in two axes by use of optical fine guidance error sensor. Can also be used for scanning missions. Has programmable multitarget capability (up to 10 targets).	1. Aerobee-170/-200 2. Aerobee-350 3. STRYPI IV 4. Black Brant VC 5. Astrobee-F	1. ITT FGES III (Startracker) 2. BBRC Celestial Error Sensor 3. GSFC Dual Reticle Startracker 4. GSFC Solar Sensor	1. Aerobee-170/-200—25.4 cm (10 in.) long; 28.56 kg (63 lb) 2. Aerobee-350—33.2 cm (13 in.) long—52.4 kg (115 lb) including separation and gas supply 3. BBVC/Astrobee-F—43.2 cm (17 in.) long; 42.2 kg (95 lb)	±3°, 3σ on coarse gyros ±1 arc-min on FGES	±0.25° at 0.1°/s (coarse gyros) ±10 arc-s at 15 arc-s/s (FGES)	Limit cycle and accuracy depend primarily on signal-to-noise (S/N) ratio obtained from FGES. System is separable from rocket on all but Aerobee-170/-200 where residual rocket pressurization gas is used to point complete rocket and payload.
2. Mark II	Aerojet Liquid Rocket Co.	Same as System 1	1. Aerobee-150/-170 2. Veronique (French) 3. Skylark (British)	1. ITT FGES II (Startracker) 2. Solar Sensor BBRC SS-100	1. Aerobee-170/-200—38.1 cm (15 in.) long; 34.1 kg (75 lb) 2. Skylark—76.2 cm (30 in.) long; 47.7 kg (105 lb)	Same as System 1	Same as System 1	Same as System 1. Rig stabilization available.
3. STRAP-IV	Same as System 1	Basically the same as System 1, additionally uses Rate Integrating Gyros (RIG) with active third-axis update to provide higher accuracy pointing at a maximum of two non-trackable targets.	Same as System 1	Same as System 1	1. Aerobee-170/-200—38 cm (15 in.) long; 37.4 kg (82.5 lb) 2. BBVC/Astrobee-F—55.8 cm (22 in.) long; 47.7 kg (105 lb) 3. Aerobee-350—33.2 cm (13 in.) long; 57.3 kg (126 lb)	Same as System 1 plus approx. ±15 min on a non-trackable target which is within 10° of a trackable star	Same as System 1 plus ±7 s at 68 s/s	System is separable from rocket on all RIG but Aerobee-170/-200 where residual rocket pressurization gas is used to control complete rocket payload.

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Table 3 (continued)

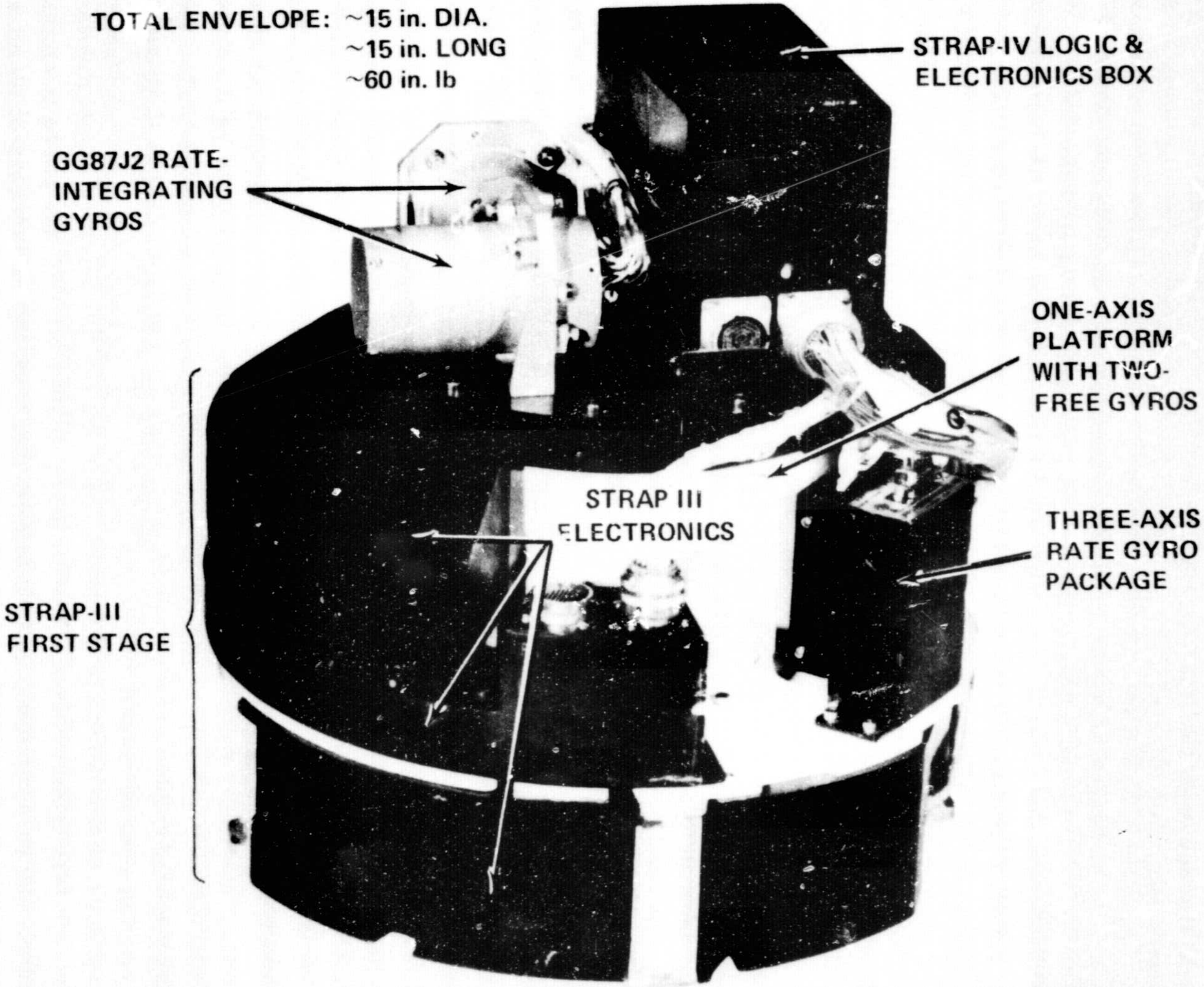
Characteristics of Sounding-rocket Attitude Control Systems (ACS)

Control System	Cognizant Agency (Manufacturer)	Operational Mode	Rocket Availability	Fine Guidance Error Sensor (FGES)	Approx. Length and Weight (Exclusive of FGES)	Expected Pointing Accuracy	Limit Cycle Noise and Frequency (Typical)	Notes
4. SPARCS	NASA/GSFC (Lockheed Missiles and Space Co.)	Despin and coarse stabilization on Sun achieved with error signal from coarse solar cells and a two-axis magnetometer. Final stabilization and fine pointing in pitch and yaw is controlled by a fine solar sensor with roll remaining under magnetometer control.	1. Aerobee-170/-200 2. Aerobee-350 3. Black Brant VC 4. Astrobee-F	1. Lockheed Sun Sensor 2. Intermediate Sun Sensor (Exotech, Inc.) 3. Solar Experiment Alignment Sensor (Exotech, Inc.)	1. Aerobee-170/-200—15.2 cm (6 in.) long; 15.8 kg (35 lb) 2. Black Brant VC—15.2 cm (6 in.) long; 20.4 kg (45 lb)	Pitch-yaw: 15 arc-s Roll: ±2°	Pitch and yaw: ± 0.5 arc-s at 10 arc-s/s Roll: 1/5° stability	System is separable in all cases with integral cold-gas supply. Has adjustable solar raster scan and roll angle adjustment capability. Also can offset point to different portions of the solar disk.
5. SPT	(Space Vector Corp.)	Two-axis (rocket continues to spin) gyro-referenced system using one or two jets firing normal to the longitudinal axis of the rocket or payload in a programmed direction.	1. Nike-Tomahawk 2. Nike-Javelin 3. Black Brant VC	Can be used with an Electro Optics Solar Sensor to correct gyro reference for solar pointing mission.	1. Nike-Tomahawk—38 cm (15 in.) long; 9.52 kg (21 lb)	Better than 3°	Pitch and yaw: ± 1° at 0.3 Hz Roll: Spinning	
6. MARK-III	(Aerojet Liquid Rocket Co.)	Three-axis cold-gas jet solar pointing system using one strapped down two-axis free gyro for roll control and to establish the acquisition plane. Coarse solar cells and fine Sun sensor complete the solar capture and stabilization sequence.	1. Aerobee-170/-200	BBRC SS-100 Solar Sensor	1. Aerobee-170/-200—15.2 cm (6 in.) long; 23.6 kg (52 lb)	Pitch and yaw: ±1 arc-min Roll: ±3°	Pitch and yaw: ±1 arc-s at 15 arc-s/s Roll: ±0.25° at 1/10°/s	Points entire rocket at Sun using residual rocket pressurization gas. Has provision for offset pointing on solar disk and raster scan program. Uses much of System 2 hardware.
7. DACS	Ball Bros. Res. Corp.	Uses an onboard g.p. digital computer to process error signals from one axis platform containing three RIG's. Computer has capacity to process experimenter data.	Configured for 15-in. Aerobee but adaptable to any larger rocket.	Same as System 1	1. 27.3 cm (10.75 in.) long; 26.3 kg (58 lb); 38 cm (15 in.) dia. Aerobee config. plus separable pneumatics system	±20 arc-min inertial ±1 arc-min on FGES RIG drift ≤2 arc-min per min	±5 arc-s on FGES	System is completed but has not been flown as of this time. No mission is currently planned. Computer has 2048 (20-bit) word memory.

on/off jet commands in proportion to the magnitude of the error signal from the position and rate sensors. The error sensors and logic implementation vary significantly, primarily due to the original mission and precision for which the system was designed or developed.

Most of the systems have evolved special purpose adaptations to handle missions for which they were not designed. Often, the special purpose adaptations come into common use because a new capability for conducting different types of scientific investigations was created. An example of this was the Solar Eclipse Mission of March 1970. To observe the totaliy eclipsed Sun with high stability (±5 arc-s of jitter) and accuracy, a Stellar Tracking and Rocket Attitude Positioning (STRAP-III) control system was equipped with a solar cresent error sensor and a pair of low-drift rate (<1°/hour), high resolution, rate-integrating gyroscopes. The system was launched just prior to the period of total darkness (eclipsed Moon hiding the Sun—totality) and maneuvered to the partially eclipsed Sun position on its standard wide-angle gyroscopes. Control in two axes was then switched to the solar crescent sensor and the vehicle was aligned in a precise manner with respect to the solar crescent. Just before totality, the system switched control to the rate-integrating gyroscopes and maintained the required precise pointing and stability throughout totality. Third contact was observed before re-entry of the rocket payload. A system called STRAP-IV with multi-target maneuvering capability under closed-loop rate-integrating gyroscope control is in use by GSFC's Sounding-rocket Division to enable two-axis fine stabilization on x-ray sources. Figure 7 shows the STRAP-IV ACS. In short, much of the NASA work with sounding-rocket control and stabilization has been evolutionary as the demands for more control capability forced system changes and improvements.

None of the systems is a precision three-axis control system of the type that is required for some of the x-ray pointing and star field astronomy experiments which are being considered for the near future. All of the systems have only two axes of fine-pointing capability with much coarser pointing accuracy in the third axis. There is a need for a three-axis fine pointing system with the capability of using two stellar error sensors to correct (in three axes) a low drift-rate inertial reference. The first sensor could be used to correct in pitch and yaw, and the second sensor could provide the roll correction. This would allow simultaneous observations of different positions on the celestial sphere without requiring a trackable source. Preliminary design studies and some component evaluation are in progress. It is believed that pointing accuracies of about 1 arc-min can be obtained at reasonable cost and moderate complexity. By using fluidic proportional thrusters rather than the on/off controllers used in most present systems, sub arc-second stability on target can be achieved.



NOTE: THIS SYSTEM HAS FLOWN FOUR TIMES; TWO AS A STRAP III, TWO AS A STRAP IV

Figure 7. STRAP-IV Sounding-rocket Attitude Control System (ACS)

7. RECOVERY SYSTEMS

The NASA/GSFC Sounding-rocket Program now provides payload recovery capability for all of its operational vehicles. The basic data for these systems are presented in Table 4. The Aerobee-150/-170/-200 and Astrobee-F systems are all 38.1 cm (15 in.) in diameter and mount at the aft end of the payload. The Nike-Tomahawk and Aerobee-350 systems also mount on the aft end of the payload. The Black Brant VC system is available in an ogive nose configuration as well as a configuration which is mounted at the base of the payload. Water recovery capability is available on the Aerobee-150/-170/-200 and the Nike-Tomahawk.

NASA sounding-rocket systems provide severance or mechanical separation of the payload at atmospheric exit or re-entry depending on the vehicle type and/or experiment requirements. The recovery body is allowed to fall freely to approximately 6000 m (20, 000 ft) at which time a barometric sensing system initiates deployment of the first-stage decelerator. The first-stage decelerator stabilizes the recovery body and reduces the dynamic pressure to a safe level for deployment of the main parachute. A pyrotechnic staging line cutter is actuated at a predetermined time after first-stage deployment. This releases the first stage and extracts the final-stage parachute.

Water recovery system operation is similar to land recovery. A flotation bag is located on a tow line between the parachute and the recovery body, or incorporated at the parachute vent point. The flotation bag is inflated with carbon dioxide (CO_2), or it is ram actuated and the bag inflated during the final descent phase. It is fully inflated at water impact. Figure 8 shows a typical sequence of operation. Figures 9 and 10 show photographs of the final stages of a typical land recovery operation.

In addition to the payload recovery capability outlined earlier, several systems are in various stages of development. These include a 454-kg (1000-lb) water recovery capability for the Black Brant VC and the Astrobee-F, a 907-kg (2000-lb) land and water recovery capability for the Aries, and a high-altitude slow-descent system for the Hawk.

Table 4

NASA/GSFC Sounding-rocket Recovery Systems

System Identification	Type	Recovery Body Weight [kg (lb)]	Recovery System Weight [kg (lb)]	Vehicle Separation System	First-stage Decelerator Deployment System	Main Parachute Deployment System	Parachute Characteristics: First-stage Type	Parachute Characteristics: Main Parachute Type	Parachute Characteristics: Flotation Bag	Parachute Characteristics: Sea-level Rate of Descent [m/s (ft/s)]
Aerobee-150/-170/-200	Two-stage land	226.7 (500) 340 (750)	24.9 (55) 20.1 (62)	Shaped charge or mechanical	Shaped charge	Pyrotechnic staging line cutter	2.66-m (8.4-ft) dia. conical ribbon	7.3-m (24-ft) 8.53-m (28-ft) dia. flat circular		10.66 (35) 11.58 (38)
Aerobee-150/-170/-200	Two-stage water	226.7 (500) 340 (750)	31.7 (70) 34.9 (77)	Shaped charge or mechanical	Shaped charge	Pyrotechnic staging line cutter	2.66-m (8.4-ft) dia. conical ribbon	7.3-m (24-ft) 8.53-m (28-ft) dia. flat circular	0.212-m^3 7.5-ft^3 bag CO_2 inflation	10.66 (35) 11.58 (38)
Aerobee-350	Two-stage land	498.7 (1100)	52.1 (115)	Shaped charge and manacle ring	Drogue gun	Pyrotechnic staging line cutter	3.65-m (12-ft) dia. conical ribbon	14-m (46-ft) dia. cross		9.14 (30)
Black Brant VC	Two-stage land	340 (750)	34.9 (77)	Manacle ring	Drogue gun	Pyrotechnic staging line cutter	2.6-m (8.5-ft) dia. conical ribbon	8.53-m (28-ft) dia. flat circular.		11.58 (38)
Black Brant VC ORSA	Two-stage land	340 (750)	43 (95)	Manacle ring	Drogue gun	Pyrotechnic staging line cutter	2.6-m (8.5-ft) dia. conical ribbon	8.53-m (28-ft) dia. flat circular		11.58 (38)
Nike-Tomahawk	Two-stage land	136 (300)	29.9 (66)	V-band	Drogue gun	Pyrotechnic staging line cutter	1.64-m (5.4-ft) dia. conical ribbon	7.19-m (23.6-ft) dia. ring-sail		9.14 (30)
Nike-Tomahawk	Two-stage water	122.4 (270)	31.7 (70)	V-band	Drogue gun	Pyrotechnic staging line cutter	1.06-m (3.5-ft) dia. guide surface	2.4-m (8-ft) dia. guide surface	0.198-m^3 (7-ft^3) ram air bag with 0.099-m^3 (3.5-ft^3) CO_2 bag inside	21.3 (70)

Table 4 (continued)

NASA/GSFC Sounding-rocket Recovery Systems

System Identification	Type	Recovery Body Weight [kg (lb)]	Recovery System Weight [kg (lb)]	Vehicle Separation System	First-stage Decelerator Deployment System	Main Parachute Deployment System	First-stage Type	Parachute Characteristics		
								Main Parachute Type	Flotation Bag	Sea-level Rate of Descent [m/s (ft/s)]
Astrobee-F	Two-stage water	335.5 (740)	38.5 (85)	Manacle ring	Drogue gun	Pyrotechnic staging line cutter	2.66-m (8.4-ft) dia. conical ribbon	8.53-m (28-ft) dia. flat circular	0.424-m^3 (15-ft^3) bag CO_2 inflation	11.58 (38)
Astrobee-F/ Aerobee-200	Two-stage land	226.7 (500) 340 (750)	34.45 (76) 36.3 (80)	Manacle ring	Drogue gun	Pyrotechnic staging line cutter	2.66-m (8.4-ft) dia. conical ribbon	7.3-m (24-ft) 8.53-m (28-ft) dia. flat circular		10.66 (35) 11.58 (38)
Astrobee-F/ Black Brant VC	Two-stage water	453 (1000)	Under development	Manacle ring	Drogue gun	Guillotine cable cutter	2.43-m (8.0-ft) dia. conical ribbon	7.3-m (24-ft) dia. guide surface	0.99-m^3 (35-ft^3) ram air	15.24 (50)
Aries	Two-stage water	906 (2000)	Under development	Manacle ring	Drogue gun	V-band release	3.1-m (12.5-ft) dia. ribbon	15.5-m (51-ft) dia. cross	0.99-m^3 (35-ft^3) ram air inflated bag	15.24 (50)
Aries	Two-stage land	906 (2000)	Under development	Manacle ring	Drogue gun	V-band release	3.1-m (12.5-ft) dia. ribbon	22-m (66-ft) dia. cross		7.62 (25)
Hawk	High-altitude single stage	45.34 (100)	Under development	Manacle ring	None	V-band release	None	20.5-m (63.5-ft) dia. cross		2.74 (9)

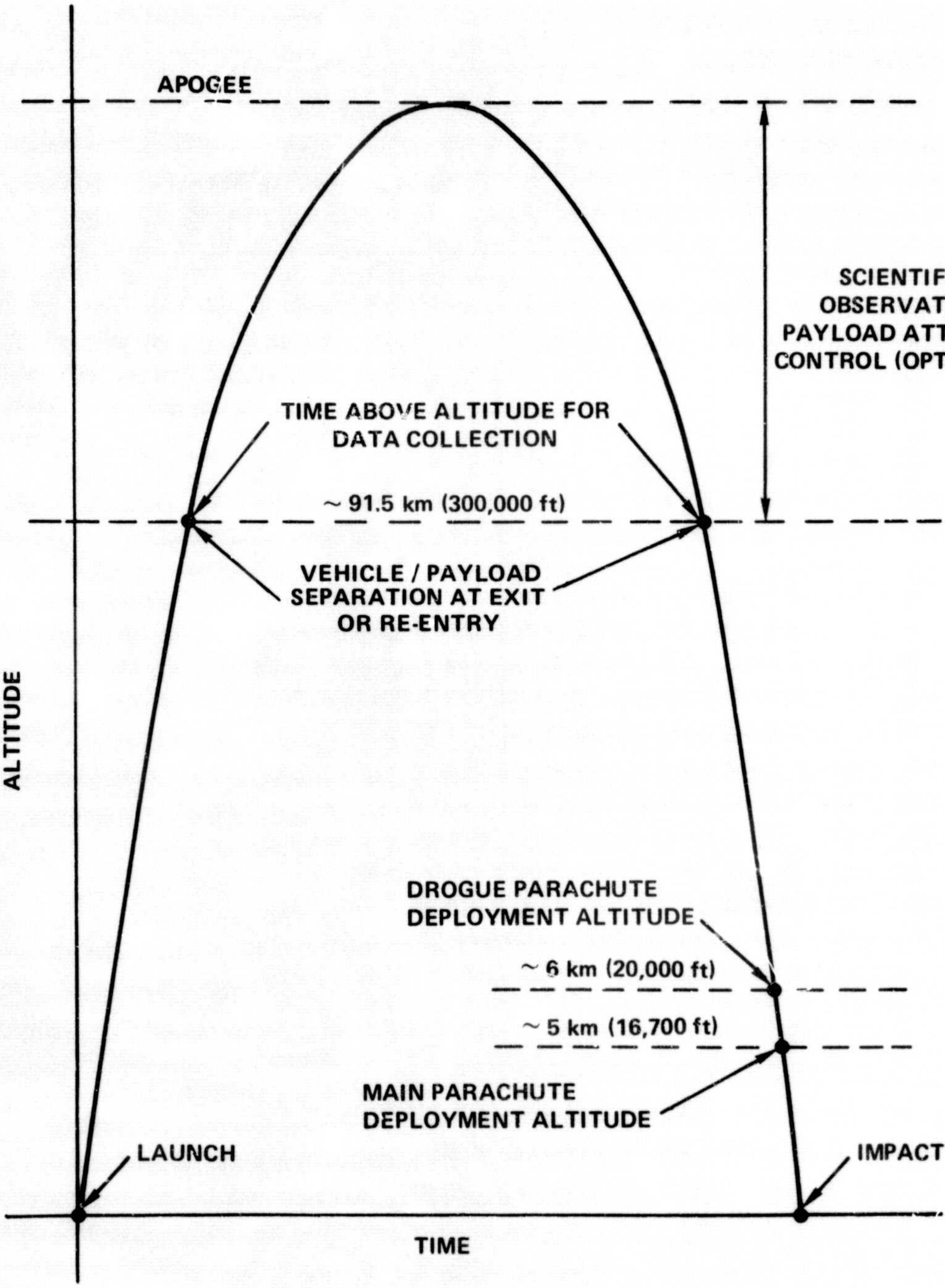


Figure 8. Typical Recovery Mission Profile

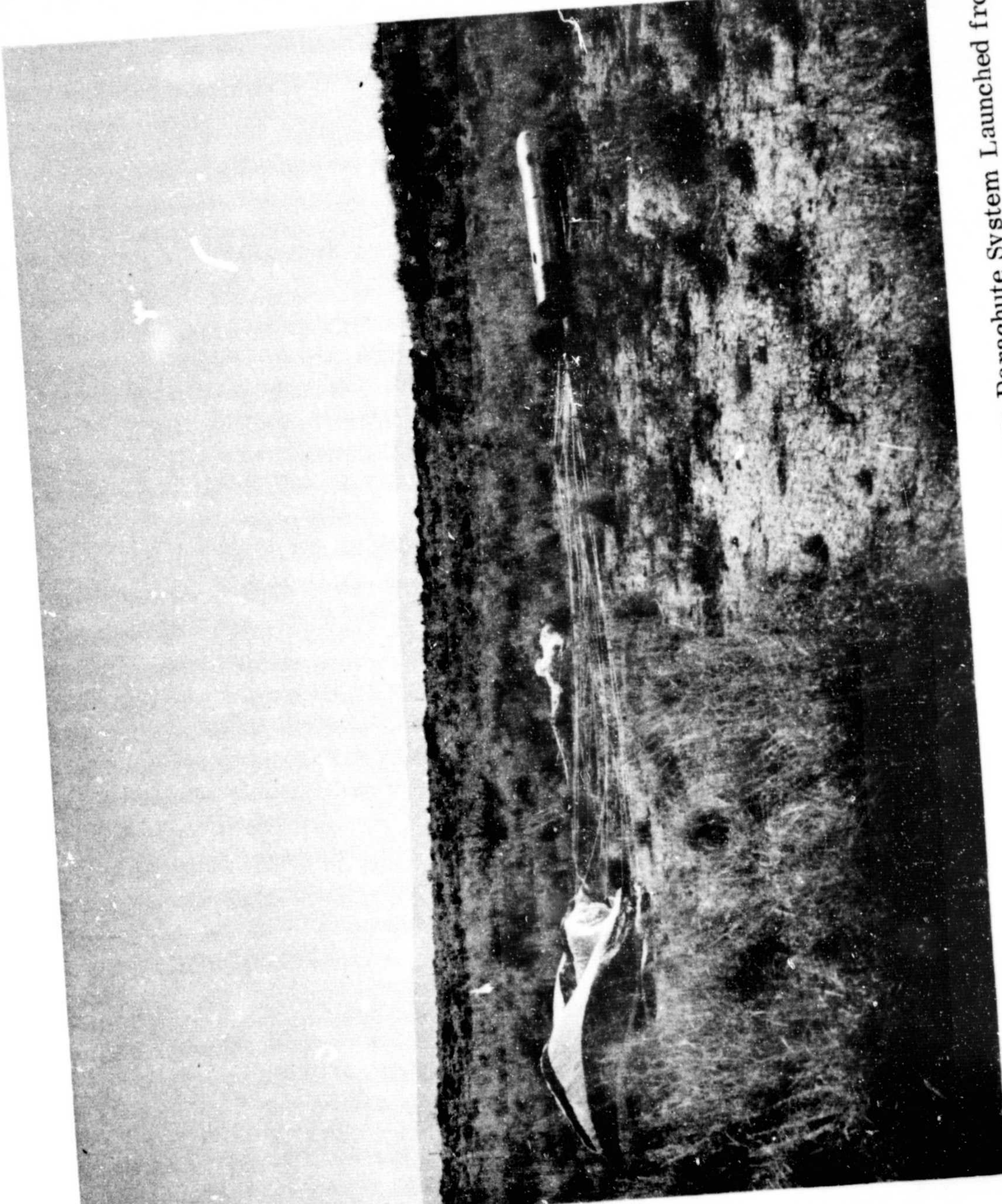


Figure 9. Aerobee-200 Rocket NASA 26.014 CS Recovery Parachute System Launched from White Sands Missile Range (WSMR), New Mexico, January 16, 1974

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Figure 10. Loading Aerobee-170A Rocket NASA 13.075 UG on Helicopter, May 25, 1973

8. TELEMETRY/INSTRUMENTATION

Most experiment data are recovered from sounding-rocket flights by telemetry techniques. There are two principal types of telemetry systems currently used on NASA sounding rockets: (1) frequency modulation/frequency modulation (FM/FM) and (2) pulse-code modulation/frequency modulation (PCM/FM). A summary of these two systems is presented in Table 5. Specialized telemetry configurations, considered unique to a particular type of experiment, are also used to accommodate wideband data, such as television and rubidium magnetometers.

More than one telemetry system can be and usually is flown on a single sounding rocket. A small sounding rocket with few measurement requirements might fly one FM/FM system with only 10 channels. A large vehicle with very extensive measurement requirements might fly, for example, two PCM/FM systems and two FM/FM systems—a total of several hundred data channels and a total sampling rate of approximately 80 kHz. Figure 11 is a photograph of a typical telemetry system.

Table 5

Summary of the Two Common Types of Telemetry Systems

Item	FM/FM	PCM/FM	
		Analog	Digital
(1) Number of channels	14 (typical) (can be up to 18)	448 max	448 max
(2) Total frequency response	10 kHz (typical)	20 kHz (word sampling rate)	20 kHz (word sampling rate)
(3) System accuracy	1 percent	0.2 percent	0 percent
(4) Sampling technique	Continuous	Discrete	Discrete
(5) Input signal levels	0 to 5 V or -2.5 to +2.5 V	0 to 5 V	Parallel, serial, or counts 0 = 0 V 1 = 5 V
(6) Input impedance	1 Meg	1 Meg	TTL
(7) Power*	35 W	36 W	
(8) Size*	94 cm^2 (37 in.^{2})	127 cm^2 (50 in.^{2})	
(9) Weight*	1.58 kg (3.5 lb)	1.81 kg (4 lb)	

*These parameters include the modulator, calibrator, and transmitter.

As shown in Table 5, the power, size, and weight requirements of the two types of systems are roughly the same. The input signal levels and the input impedance are the same except for the optional ±2.5-V range on FM/FM. Data capacity and sampling rates are normally higher on a PCM/FM system than on a typical FM/FM system; but an FM/FM system would be preferred for high-frequency continuous spectrum data characteristics, for example, vibration measurements.

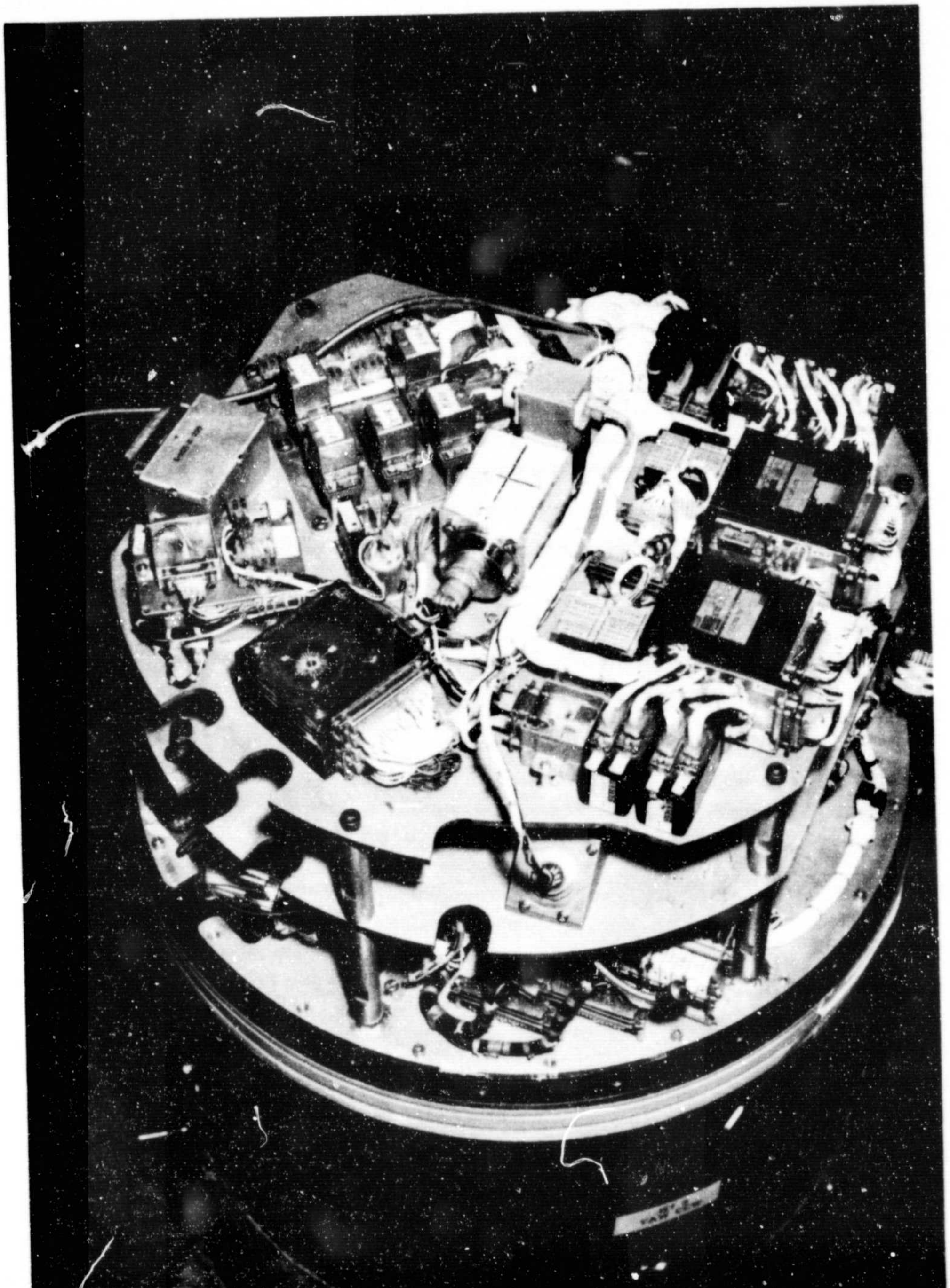

Figure 11. Aerobee-350 Rocket NASA 17.012 CG Telemetry Buildup, March 11, 1974

Two primary differences exist between FM/FM and the digital systems. The first difference is system accuracy. An order-of-magnitude increase in accuracy is gained by switching from FM/FM to PCM/FM due to the improved noise immunity inherent in digital encoding. The second difference is in the data reduction techniques used for the FM/FM system versus the digital system. The digital system data are directly usable by a digital computer and thus, data reduction is automated. The FM/FM system data normally, however, are reduced by hand from paper records. Some digitization systems will provide digital computer tapes from FM/FM data, but they are not widely used. Normally, an experimenter who wants automated data reduction will use a PCM/FM system.

A brief description of each type of system and a discussion of the data reduction processes follows.

8.1 FM/FM

A radio frequency (RF) carrier frequency, either assigned to S-band (2200 to 2300 MHz) or P-band (225 to 260 MHz), is frequency modulated by the mixed composite signal from all assigned standard Inter Range Instrumentation Group (IRIG) subcarriers. Each subcarrier Voltage Control Oscillator (VCO) in turn is frequency modulated by the transducer voltage with a data frequency response determined on a proportional basis with respect to the subcarrier's center frequency. A typical system will employ about 14 subcarriers, although up to 18 are possible, with data frequency response typically ranging from approximately 15 Hz to 5,000 Hz. Figure 12 is a simplified block diagram of the FM/FM system.

8.2 PCM/FM

This type of telemetry, using the same RF carrier assignments as FM/FM, is shown in block diagram form in Figure 13. The data encoding system consists of 448 channels with a sampling rate of 20 kHz/s and a bit rate of 200 kHz/s.

All data start as, or are converted to, digital 9-bit words to which a parity bit is added. Accuracy is 100 percent on digital transducers and 99.8 percent on analog signals, that is, the analog-to-digital converter has an accuracy of ±0.1 percent.

Data input can be serial digital, parallel digital, pulse rate, analog (0 to 5 V), or time-event pulse. Available modules are described completely.* The basic

*"Sounding Rocket Airborne PCM System," NASA X-743-73-385, December 1973.

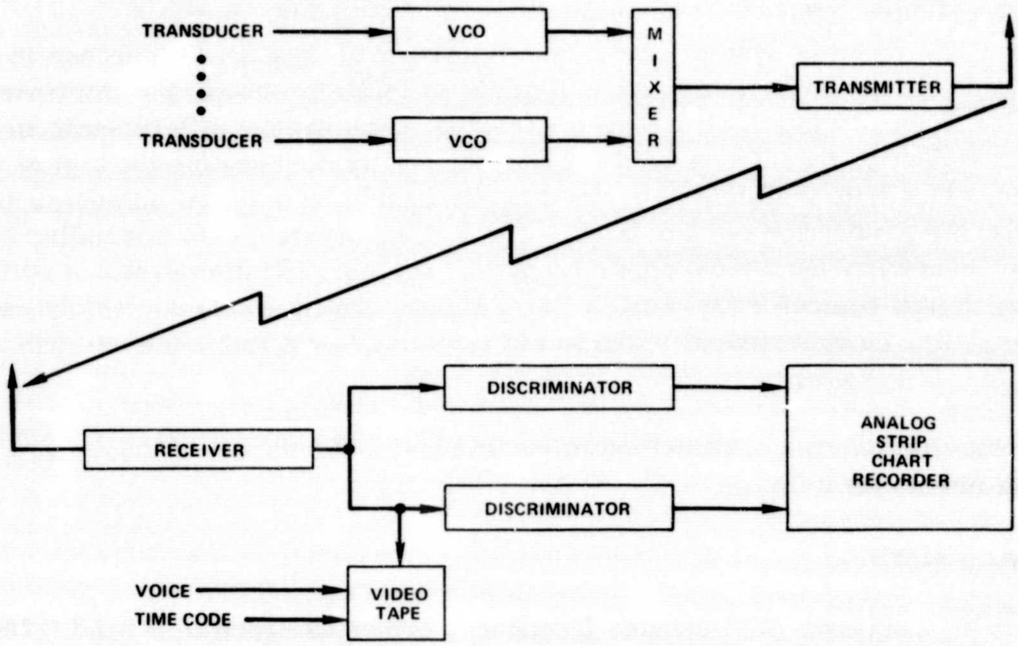

Figure 12. FM/FM System

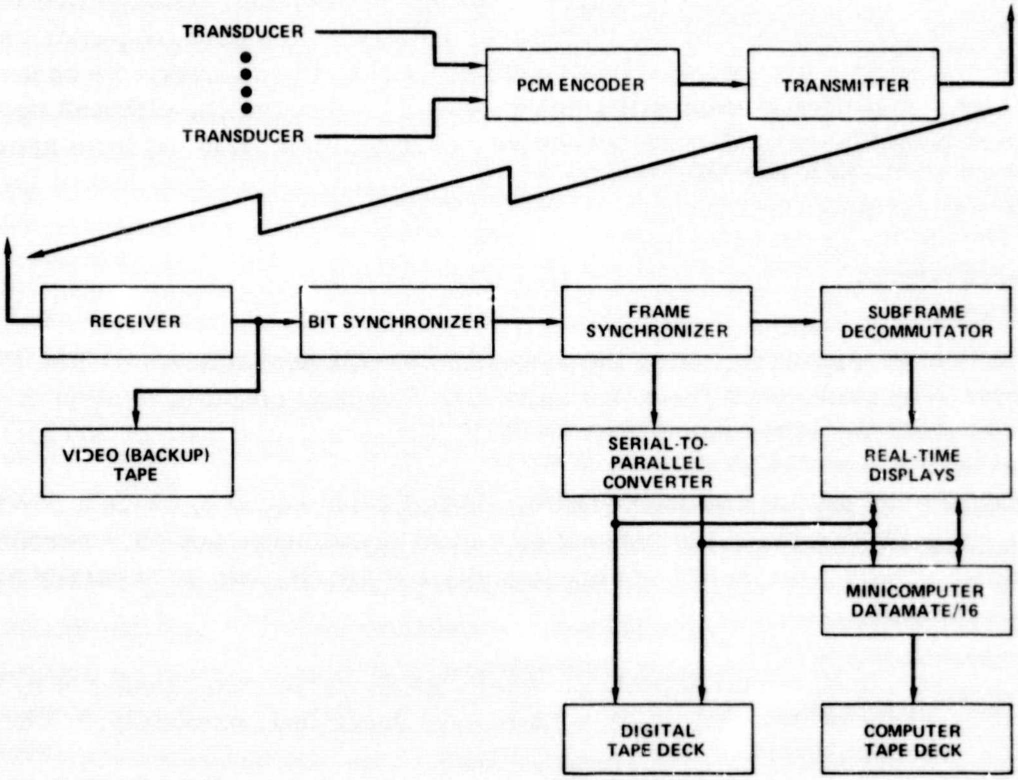

Figure 13. PCM/FM System

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format of the data is 512 channels (16 by 32) of which 64 are used for synchronous and subframe count leaving 448 channels available to the experimenter. The total sampling rate is 20,000 words/s. Any one of the 448 experimenter data channels is sampled at 39.06 samples/s, but channels can be supercommutated easily to provide any desired overall sampling rate up to 20 kHz/s. Ground-support equipment includes strip chart records and a one channel analog-digital-binary readout display. The GSFC/SRD and two portable stations include a mini-computer-based data reduction system. Computer compatible (9-track, 800 bpi) magnetic tapes are provided for all PCM/FM flights.

8.3 SOUNDING-ROCKET TELEMETRY ANTENNAS

Nearly all sounding-rocket telemetry antennas that are currently used can be classed into one of two types: flush and nonflush mounting. As vehicle performance increases, the flush mount types become more desirable from the aerodynamic standpoint. Shifts to S-band frequencies make the flush mount antenna more reasonable in size with a less bulky connection to the vehicle structure. In spite of the fact that the flush mount antenna has a characteristic power-null fore and aft of the vehicle, it is being more widely used with good results.

One of the most widely used nonflush antennas is a basic element called the "quadraloop." Its name is derived from its geometric configuration, that is, quarter-of-a-loop. It is basically a shorted quarter-wave transmission line which is dielectrically loaded to achieve physical shortness. The elements are always employed in pairs and are mounted diametrically opposite on the rocket. One element is always fed 180° out-of-phase with respect to the other element when the wavelength-to-rocket diameter ratio is greater than one. In cases where the wavelength-to-rocket diameter ratio is less than one, perturbations in aft radiation coverage are experienced. In this case, other types of element phasing must be considered.

Another very common nonflush antenna is a swept-back radiator which is nothing more than a quarter-wave rod canted back at an angle of 45° to 60° with respect to the axis of the vehicle. In general, there are four of these elements, each progressively fed 90° out-of-phase to give a circular polarization component. In cases where circular polarization is used, the sense of circular-wave rotation must be in the proper direction to avoid cross-polarization which would result in a 10-dB decrease in signal. In most sounding-rocket antenna work, the right-circular polarization is the most conventional. It is defined as a clockwise rotating field looking aft of the vehicle. The 3-dB gain achieved in using right-circular polarization on sounding-rocket vehicles is sometimes weighed against the increased drag experienced by the addition of two more radiators. With only two diametrically opposite elements, linear polarization is experienced. If right-circular polarization is used on the ground in a receiving mode, cross-polarization will not be experienced. In nearly all instances, circularly polarized receiving antennas are used for the reception of scientific data from the sounding rocket.

While all the goals of an ideal multipurpose antenna have not been reached, new improvements in vehicle antenna design are continuing and are being tested.

8.4 INSTRUMENTATION

Telemetry/instrumentation systems, designed for sounding-rocket applications, provide the experimenter with a variety of services in addition to telemetry data acquisition. These support services are generally classified as timing, power, and control. Depending on the nature of the experiment, specific circuits and/or components are incorporated into the telemetry/instrumentation system to fulfill specific experiment requirements. For example, a particular experiment may require a timed command to energize a high-voltage supply, including a positive "hold-off" of high voltage during rocket ascent through the corona region; +28 V and +15 V unregulated dc power to the experiment, including "external" (blockhouse power supplies) and "internal" (instrumentation battery packs) control distribution and monitors; and perhaps a regulated +5-V dc supply for an experiment sensor. These requirements would be satisfied by incorporating into the telemetry/instrumentation, specific circuits and components configured to provide redundancy in timing and power distribution. System design emphasis is applied to provide as much reliability as possible while restricting weight and volume requirements to practical limits.

Included as part of system instrumentation are other components to measure vehicle performance and environment, for example, pressure gages, accelerometers, "angle-of-attack" instruments, thermocouples, and so on. Additionally, a radar beacon is normally included to provide a tracking assist to range radars.

Aspect and attitude sensors, described in the following section, are included to provide payload orientation data for correlation with experiment data.

9. ATTITUDE, POSITION, AND COMMAND (APC) INSTRUMENTATION

Knowledge of the geodetic position, and/or geodetically or celestially related orientation of experiment reference axes is often a prerequisite to correct interpretation of experimental data. In other cases, this type of information can help explain anomalies or unexpected data. APC instrumentation and support services are aimed at relieving the individual experimenter from the burden of measuring and reducing this type of prime supplementary data.

With the increasing maturity of the SRD and the experimenters, the missions have become increasingly sophisticated. It is expected that this trend will continue and create further requirements for real-time selection of look-angle, sensitivity, and other experiment variables. To provide this capability, a command supplement to the APC tracking system has been developed. Up to 31 bi-state commands are available for use. In addition, experimenter-supplied command tones generally can be accommodated by the tracking interrogation link.

Payload orientation (attitude) can be derived directly from inertial platform data or from combined solutions of aspect measurement. One or more of the following types of instrumentation are normally incorporated into each payload for determining aspect or attitude of the rocket during flight.

- Three-axis inertial platform

  Attitude accuracy: $\pm 1.5^\circ$ in 6 min
  Resolution: $\pm 0.3^\circ$

- FM/FM-compatible solar sensor

  Aspect accuracy: $\pm 1.5^\circ$
  Resolution: $\pm 1^\circ$

- PCM-compatible solar sensor

  Aspect accuracy: $\pm 0.5^\circ$
  Resolution: $\pm 0.3^\circ$

- PCM-compatible lunar sensor

  Aspect accuracy: $\pm 1^\circ$
  Resolution: telemetry limited
  Sensitivity range: new Moon $\pm 45^\circ$ (elongation)

- Horizon sensor

  Aspect accuracy: approximately $\pm 2^\circ$
  Resolution: telemetry limited

- Magnetometers (two and three axis)

  Aspect accuracy: ±3° RMS
  Resolution: telemetry limited

10. TRACKING AND COMMAND INSTRUMENTATION

Payload position measurement is accomplished by use of the Telemetered Range, Angle, and Command Systems (TRACS) airborne and ground instrumentation systems with the airborne telemetry system in support. TRACS is a post-flight analytical tool. Under nominal signal conditions, the uncertainty of positional information is ±8.5 m rms. For simplicity and economy, TRACS has traded ambiguity for precision and accuracy. TRACS records must be examined for coarse data loss and appropriately edited prior to final arithmetic processing. It is planned to add ambiguity removal in the near future to provide real-time positional data for command decisions.

Range measurement is accomplished by transmitting a reference tone to the payload by a frequency-modulated 550-MHz carrier. This is received and demodulated in the payload where it is combined with the telemetry modulation and retransmitted by the telemetry transmitter. The tracking tone is filtered from the telemetry video and compared in phase to the reference tone. Prior to launch, bias or fixed-phase relationships are cancelled out; thus, post-launch phase changes are an accurate measure of slant range, and Doppler periods are a measure of slant velocity. With relaxed positional accuracy requirements, a measurement of slant range can be made using a stable oscillator in the payload in place of the tone-range receiver. This is termed "single path ranging."

Direction cosines of the slant-range vector are derived by two mutually orthogonal 16-wavelength interferometer systems. In each system, the relative electrical phase of the telemetry carrier is measured and processed to provide the angle of arrival of the carrier wavefront.

Slant range, vector angles, and geodetic data are arithmetically combined to provide very accurate geodetic positions.

The command system uses the tracking reference transmitter and airborne receiver as communication components. Up to five command tones plus a parity tone are processed logically and combined binarily to provide up to 31 commands at 1.5-s intervals. At present, command must be initiated at the TRACS ground station; however, user control is anticipated in the near future.

11. ANCILLARY SUPPORT—CELESTIAL TO GEODETIC SOLAR/LUNAR PREDICTION

To help the experimenter select his launch window as a function of relative solar/lunar geodetic position and lunar phase, a program has been developed to provide such data in graphic form. Reduction of double source aspect data to geodetic or celestial pointing information is available through GSFC/SRD.

12. POSITION DATA REDUCTION

Quick-look information, such as maximum altitude, time-of-apogee, impact range, and azimuth are available within one-half hour of termination of the flight.

Preliminary data reports and plots of raw data generally are available within one day of the arrival of data tapes at the WSMR TRACS. Processing of data, smoothing, and deriving special data formatting, such as $\dot{X}$, $\dot{Y}$, and $\dot{Z}$, requires a somewhat longer time. In general, a formalized final report can be expected within four to five weeks.

13. LAUNCH SITES

The locations of sounding-rocket ranges have been determined mainly by logistic and safety requirements. In some cases, such as that of the auroral site at the Churchill Research Range (CRR), ranges have been constructed specifically to undertake research on special scientific problems. A number of scientific problems involving coordinated launchings of sounding rockets from several sites have been carried out, beginning during the International Geophysical Year (IGY). During IGY, world days were set aside for coordinated launchings of sounding rockets. Through COSPAR's Working Group-II Panel* on Synoptic Sounding Rockets, synoptic scientific investigations have been proposed and worldwide cooperative flights have been undertaken. The advantages derived from the simultaneous or coordinated sounding-rocket investigations at various geographical sites have been established from studies of this nature. It is now possible to investigate problems in aeronomy by means of simultaneous or consecutive flights (from several launching sites). The study of solar-terrestrial relations and the effects of latitude variations are further examples.

*COSPAR—Committee on Space Research

The distribution of sounding-rocket sites has become more important in the correlation of observations obtained from satellites with observations of phenomena which vary with altitude. The capacity for undertaking such comparisons depends on the geographical distribution of sounding-rocket launching facilities (see Table 6) and the state of development of these facilities. By observing identical targets or phenomena at identical or appropriate times, a verification of satellite performance can be obtained. The worldwide launch capability affords observational opportunities tied to Earth-related or hemisphere-unique targets.

14. INTERNATIONAL COOPERATIVE PROGRAMS

The purpose of the Sounding-rocket Program, as related to International Cooperative Programs, is to stimulate scientific interest and technical competence in other countries. In order to stimulate interest, NASA provides sounding-rocket flight opportunities for scientists and government agencies of other countries.

During the past 15 years, 20 countries have joined with NASA in cooperative projects resulting in the launching of more than 600 rockets from ranges outside the United States. In all cases, the scientific data are shared and the results published in the open literature. The basic components of a sounding-rocket program are the scientific payload; the sounding rocket; the launching facilities and services; and the ground equipment for command, telemetry, and tracking. Division of responsibilities in International Cooperative Programs with other countries has varied to reflect the respective interests and capabilities of the cooperating parties in the specific project.

In most cases, foreign scientists propose experiments of their own development to NASA. If there is an interest in that scientific investigation, then cooperative project arrangements will be made in which NASA provides the sounding rockets, and the cooperating agency will provide both the scientific payload and range services.

Another variant has involved payloads jointly instrumented by U.S. and foreign scientists.

The development of sounding rockets by other countries has, in several cases, made it possible to fly U.S. payloads on foreign sounding rockets or to coordinate U.S. and foreign sounding-rocket launchings. Nations which have developed or are developing their own sounding rockets include Argentina, Australia, Brazil, Canada, France, India, Japan, and the United Kingdom. During 1974, cooperative sounding-rocket launches were conducted from Canada, French Guiana, Greenland, Norway, and Sweden. During 1975,

Table 6

Launch Sites

Site	Location
Argentina	
Chamical	(30.5°S, 66°W)
Australia	
Woomera	(31°S, 137°E)
Brazil	
Natal	(5°S, 35°W)
Canada	
Fort Churchill	(58.8°N, 94.3°W)
Denmark	
Sondre Stromfjord, Greenland	(66.6°N, 51.7°W)
France	
French Guiana	(5°N, 53°W)
India	
Thumba	(8.5°N, 77°E)
Kenya	
San Marco Platform	(2.9°S, 40.2°E)
Netherlands	
Surinam, Dutch Guiana	(5°N, 55°W)
Norway	
Andoya	(69.3°N, 16°E)
Pakistan	
Sonmiani	(26°N, 67°E)
Peru	
Chilca	(12.5°S, 76.8°W)
Sweden	
Kiruna	(68°N, 21°E)
Kronogard	(66°N, 18°E)
United States	
Cape Kennedy, Florida	(28.2 N, 80.6° W)
Eglin, Air Force Base, Florida	(30.4° N, 86.7° W)
Kauai, Hawaii	(21.9°N, 159.6°W)
McMurdo Sound, Antarctica	(77.9°S, 166.6°E)
Point Mugu, California	(34.1°N, 119.1°W)
Siple Station, Antarctica	(75.9°S, 83.9°W)
Tonopah, Nevada	(38.0°N, 116.5°W)
Wallops Flight Center, Virginia	(37.8°N, 75.5°W)
White Sands Missile Range, New Mexico	(32.5°N, 106.5°W)

cooperative sounding rockets were launched from Canada, Kuerguelen Islands (France), and Peru. Also during 1975, cooperative sounding-rocket agreements were begun with Canada, Denmark, Germany, the Netherlands, Norway, and Sweden.

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