Chapter 2

The NASA Sounding Rocket Program and Space Sciences

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ABSTRACT

High altitude suborbital rockets (sounding rockets) have been extensively used for space science research in the post-World War II period; the NASA Sounding Rocket Program has been ongoing since the inception of the Agency and supports all space science disciplines. In recent years, sounding rockets have been utilized to provide a low gravity environment for materials processing research, particularly in the commercial sector. Sounding rockets offer unique features as a low gravity flight platform. Quick response and low cost combine to provide more frequent spaceflight opportunities. Suborbital spacecraft design practice has achieved a high level of sophistication which optimizes the limited available flight times. High data-rate telemetry, real-time ground up-link command and down-link video data are routinely used in sounding rocket payloads. Standard, off-the-shelf, active control systems are available which limit payload body rates such that the gravitational environment remains less than 10^-3 g during the control period. Operational launch vehicles are available which can provide up to 7 minutes of experiment time for experiment weights up to 270 kg. Standard payload recovery systems allow soft impact retrieval of payloads. When launched from White Sands Missile Range, New Mexico, payloads can be retrieved and returned to the launch site within hours.

INTRODUCTION

Suborbital rocket flight systems have had a long and distinguished involvement in aeronautics and space research activities conducted by the United States. Developed during World War II, rocket propulsion capability was utilized during the immediate post-war years for both tactical R&D as well as scientific investigations. During flight test activities conducted by the U.S. Army's Bureau of Ordnance at the White Sands Proving Ground (now the White Sands Missile Range) utilizing captured, German V-2 rockets, it became obvious that this was an opportunity to gain access to space for scientific purposes. By early 1946, several defense research laboratories with support from academia began utilizing these flights with historically significant results. Early discoveries in the ultraviolet spectrum and extraterrestrial x-rays resulted from suborbital rocket investigations (DeVorkin, 1986; Greenstein, 1991). After all of the V-2's were expended in the early 1950's, the Viking and Aerobee liquid-fueled rockets were utilized for scientific research, with the Aerobee becoming the workhorse throughout the 1950's. During the late 1950's, solid propellant rocket systems were developed for scientific use, as well as for high-speed aerodynamics and re-entry aerothermodynamics research.

When NASA was established in late 1958, with a charter to perform space science research, various elements of DOD space science research efforts were consolidated and the NASA Sounding Rocket Program was implemented at the Goddard Space Flight Center (Corliss, 1971).

NASA SOUNDED ROCKET PROGRAM

The NASA Sounding Rocket Program is a suborbital space flight program primarily in support of space and earth sciences research activities sponsored by NASA. This program also provides applicable support to other government agencies as well as to international sounding rocket groups and scientists.

Since the program's beginning in early 1959, there have been more than 2,500 flight missions flown with a science mission success greater than 86 percent and a launch vehicle success rate greater than 95 percent. The program is a low-cost, quick-response effort that currently provides approximately 30 flight opportunities per year to space scientists involved in the disciplines of upper atmosphere, plasma physics, solar physics, planetary atmospheres, galactic astronomy, high-energy astrophysics, and microgravity research. These rockets are launched from a variety of launch sites throughout the world. More recently, in the early 1980's, the Sounding Rocket Program was consolidated at the Wallops Flight Facility of the Goddard Space Flight Center. The program has continued to grow in terms of average payload size/weight (now approximately 400 kilograms average) and complexity (Figure 1). State of the art flight systems make today's
rocket payloads remarkably sophisticated spacecraft that are being flown to altitudes approaching 1500 kilometers.

The scientific community served by this program is primarily comprised of university and government research groups; however, some research activities involve the commercial sector. The program has yielded numerous important scientific findings and research papers; provided a proving ground for development of satellite instruments; and, through graduate programs offered by participating educational institutions, emerging new scientists have trained and developed.

Systems and services provided to the scientific users cover the complete spectrum of support including mission management, payload design and development, launch vehicles, recovery systems, attitude control systems, payload testing and evaluation, analytical studies, launch range operations/coordinations, tracking, and data acquisition and data processing. The user is required, at a minimum, to provide NASA with a viable scientific instrument complement.

Although this program is conducted without the formal and expensive reliability and quality assurance employed in the larger and more costly orbital and deep space programs, overall mission success reliability has consistently remained between 85 and 90 percent. This informal approach, and the extensive use of military surplus motors, is instrumental in enabling the Program to support approximately 30 missions per year at relatively low cost.

The Space Physics Division of the Office of Space Science and Applications has NASA Headquarters management responsibility for the Program. Goddard Space Flight Center (GFFC) Wallops Flight Facility (WFF) has management responsibility for implementation of the program. A primary part of administering the NASA Sounding Rocket Program by WFF involves the conduct of launch operations from various world-wide launch sites. Since its inception in the late 1950's, the NASA Sounding Rocket Program has conducted launch activities virtually throughout the free world. To exemplify the extent of these activities, a list of NASA supported sounding rocket launch sites which have been and are currently being used is included in Table I. Several of these launch sites are existing, full-time launch ranges; however, mobile sites can be established at remote locations which satisfy particular science requirements, such as specific observations (solar eclipses, supernova) or operations in specific areas (auroral zones, equatorial zones, Southern Hemisphere). Sounding rocket launch operations are currently being conducted at a number of United States and foreign locations. The facilities can vary from offering comprehensive launch and payload preparation, payload recovery, and data collection capabilities - such as those at WFF and White Sands Missile Range - to austere sites equipped with mobile systems tailored to a specific campaign.
Table I. NASA Sounding Rocket Launch Locations

- Andoya, Norway - Fixed Range (Full Facilities)
- Antigua, U.K. - Mobile Range Site
- Ascension Island, U.K. - Mobile Range Site
- Barking Sands, HI - Fixed Range (Full Facilities)
- Barter Island, AK - Mobile Range Site
- Cape Parry, Canada - Mobile Range Site
- Camp Tortugueria, Puerto Rico - Mobile Range Site
- Chikuni, Canada - Mobile Range Site
- Coronie, Suriname - Mobile Range Site
- Eglin AFB, FL - Fixed Range (Full Facilities)
- El Arenosillo, Spain - Fixed Range
- Fort Churchill, Canada - Fixed Range (Decommissioned)
- Fort Greely, AK - Mobile Range Site
- Fort Sherman, Panama - Mobile Range Site
- Fox Main, Canada - Mobile Range Site
- Karachi, Pakistan - Fixed Range
- Karikari, New Zealand - Mobile Range Site
- Kerguelen Island, France - Mobile Range Site
- Keweenaw, MI - Mobile Range Site
- *Kiruna (Erange), Sweden - Fixed Range (Full Facilities)
- Kourou, French Guiana - Fixed Range (Full Facilities)
- Kwajalein, Marshall Is. - Fixed Range (Full Facilities)
- Natal, Brazil - Fixed Range (Full Facilities)
- Point Barrow, AK - Fixed Range (Decommissioned)
- Point Mugu, CA - Fixed Range (Full Facilities)
- *Poker Flat Research Range, AK - Fixed Range (Full Facilities)
- Primrose Lake, Canada - Mobile Range Site
- Punta Lobos, Peru - Mobile Range Site
- Red Lake, Canada - Mobile Range Site
- Resolute Bay, Canada - Mobile Range Site
- San Marco, Kenya - Fixed Range
- Sardinia, Italy - Mobile Range Site
- Siple Station, Antarctica - Mobile Range Site
- *Sondre Stromfjord, Greenland - Mobile Range Site
- Thumba, India - Fixed Range
- U.S.N.S. Croatan - Shipboard Range (Decommissioned)
- U.S.N.S. Range Recoverer - Shipboard Range (Decommissioned)
- *Wallops Island, VA - Fixed Range (Full Facilities)
- Western Test Range, CA - Fixed Range (Full Facilities)
- *White Sands Missile Range, NM - Fixed Range (Full Facilities)
- *Woomera, Australia - Fixed Range (Partial Facilities)

A family of standard sounding rocket launch vehicles is available in the NASA Sounding Rocket Program for use in conducting suborbital space science, upper atmosphere and other special applications research. Some of the vehicles are commercially available; others have been developed by NASA for specific applications within the program. These vehicles are capable of accommodating a wide variety of payload configurations and they provide an extensive performance envelope.

There are currently 15 operational support launch vehicles in the NASA Sounding Rocket Program; all configurations use solid propellant propulsion systems. Extensive use is made of 20 to 30 year old military surplus motors in 13 of the systems. These launch vehicles are unguided except the Aries and those which are partially guided using a modular boost guidance system, which is available to meet special requirements. During flight, all of these launch vehicles, except the Aries, are imparted with a spinning motion to reduce potential dispersion of the flight trajectory due to vehicle misalignments. Outline drawings for these 15 vehicles and their NASA vehicle numbers are presented in Figure 2.

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Figure 2. NASA Sounding Rocket Launch Vehicles

Performance characteristics for apogee altitude and weight capability and flight time above 100 kilometers for NASA sounding rocket vehicles are included in Figure 3. These data are presented for sea level launch using a launch elevation angle of 85 degrees. Aries data is for a launch from White Sands Missile Range in a standard guided flight profile.
EARLY BIOLOGICAL RESEARCH ON NASA SOUNDING ROCKETS

Suborbital rocket vehicles were used for early animal space flight research soon after World War II; however, biological flight research utilizing suborbital rocket flight platforms has not been extensive within the NASA Sounding Rocket Program. Early in 1964, Wallops Flight Facility (then known as Wallops Station) was requested by NASA Headquarters to design and qualify a small, low cost payload launch vehicle system which could be utilized as a training aid for bioscientists in support of the NASA sponsored Bio-Space Technology Training Program. The primary purpose of this flight system was to assist biological experimenters in evaluating the engineering and operational aspects of spaceflight research. In response to this request, a small animal payload was developed and integrated with a modified Arcas sounding rocket launch vehicle and recovery system (Figure 4). This payload configuration was successfully flight qualified in a test program comprised of six launches and culminated in the launch and recovery of two such payloads, each containing a laboratory white rat, in September 1964, (Early, 1966). Several annual training sessions, conducted at Wallops Station during the mid-late 1960’s, were attended by biologists associated with spaceflight-related research.

In the late 1960’s, NASA/Wallops developed a flight payload capable of providing two small animals (white rats) a choice of gravity field from 0.35 to 1.65 g during approximately five minutes of zero gravity trajectory. This research was performed by the Wenner-Gren Aeronautical Research Laboratory of the University of Kentucky and was intended to augment the NASA biosatellite program in progress at the time (Lange and Belleville, 1971). The program was expected to expand existing knowledge on the morphological and physiological responses of organisms to microgravity. The rocket-borne program was proposed to investigate gravitational requirements of earth organisms by supporting the development of techniques to perform behavioral experiments in orbit. Experimental animals could vary the amount of gravity experienced, thereby demonstrating a preference for a particular gravity level. Four of these payloads (Figure 5) were successfully launched during the period from December 1967 through May 1969.
For new NASA sounding rocket payloads, the overall design effort is generally an intense activity; the Principal Investigators and their support staff work very closely with the NASA team assigned to the project. Mechanical and electrical design elements must be integrated with close attention to proper interfaces between all payload subsystems.

The controlled environment for payloads on earth abruptly changes at launch. Great variations in temperature, acceleration, atmospheric pressure, vibration and other extreme conditions are encountered. The specific flight environment for any given flight demands consideration in the design and construction of successful payloads. The principal environmental factors to be considered are:

- vibration (random, sinusoidal)
- transient shock
- acceleration (3-axes)
- thermal loads
- pressure changes
- acoustic inputs.

A major parameter to be considered in the design phase is the longitudinal and lateral loads imparted due to rocket motor thrust, steady state spin rates and abrupt changes in spin rate due to despun devices. Another major flight environment factor is the vibration induced by rocket motor burning. Longitudinal acceleration levels depend on the specific type of launch vehicle used but can exceed 40 g's for the Taurus-Tomahawk vehicle. Unguided sounding rocket launch vehicles fly with a spinning motion to reduce the flight trajectory dispersion due to misalignments, most vehicles do not exceed 6-7 cycles per second. The effects of spin-induced loads should be considered when components are located near the payload external skin on large diameter designs. Most electronic devices utilize relatively small, lightweight circuit boards and components. When soldering is properly performed, and a conformal coating applied, problems due to mechanical loads are very infrequent.

The vibration environment depends on the type of launch vehicle and the mass and structural characteristics of the overall payload. Vibration testing is one of the key elements involved in qualifying a payload for rocket flight; all payloads must pass flight acceptance vibration tests. Vibration test specifications are a function of the type of launch vehicle used and are largely based on actual measured vibration levels during launch.

Typically, sounding rocket launch vehicles reach very high speeds traveling through the earth's atmosphere. Surface heating at hypersonic speeds is significant due to the friction encountered flying through

Figure 5. Gravity Preference Payload

SOUNDING ROCKET PAYLOAD DESIGN FEATURES AND CONSIDERATIONS

Suborbital rocket payloads are designed to maximize the relatively short time that they spend in the space environment. In general, payloads are designed to utilize the situation of actually being above the sensible atmosphere to perform observations and make measurements or to exploit the condition of free-fall and the attendant microgravity environment. Current design practice for suborbital rocket payloads, used by NASA and the DOD, has resulted in extremely complex, sophisticated spacecraft. Many suborbital payloads used in the NASA program weigh in excess of 500 kilograms (1,100 pounds) and are comparable to explorer-class orbital space craft in design complexity. The principal design features that characterize suborbital payloads are:

- high data-rate telemetry
- real-time up-link command
- TV down-link
- active rate-control
- highly reliable recovery
- modular experiment accommodation
- centralized on-board power and control.
the air mass. In addition, atmospheric heating is encountered when a payload re-enters the atmosphere from space. Even though payload exterior skin surfaces experience relatively high temperature rises due to ascent aerodynamic heating, the temperature of inert internal components does not vary greatly over the course of a typical flight. This factor depends primarily on where and how components are mounted relative to the payload skin. Heating of electronic components due to operation over long time periods, e.g. during preflight check out, can be more severe. While the payload temperature may remain fairly constant during flight, hot spots within equipment may develop if the vacuum of high altitudes impedes the heat flow from components. Specially designed heat paths may be required to ensure overheating does not occur. Furthermore, when rocket payloads rapidly ascend within the atmosphere during launch, ambient atmospheric pressure drops quickly to essentially zero. Payloads are generally designed to vent internal air. Barometric switches are often utilized for switching functions in payload electrical subsystems. Some types of payload components may not tolerate low atmospheric pressures; if the experiment must be subjected to vacuum, good vacuum design practices must be utilized. The two most common undesirable effects of vacuum are reduced heat transmission and corona. Both of these problems are relatively easy to overcome when anticipated. Another design consideration which can degrade data is outgassing which occurs, to some extent, through the entire flight profile of suborbital payloads. The selection of suitable materials and techniques can minimize outgassing.

Most data are obtained from sounding rocket payloads by means of a telemetry system which formats and transmits the scientific and housekeeping data. This system can also provide control signals to the experiment and provide timing and power if desired. Systems vary in complexity from a single link with no command to systems containing numerous down links and up link commands. Almost all systems operate with S-band (2200 to 2300 MHz) down links and 550 MHz up links. 1680 MHz is used occasionally for down links on some of the smaller rockets.

Digital techniques are the most common method of transmitting data from a sounding rocket to the ground station; however, analog transmission is still being utilized. Bi-phase Pulse Code Modulation (PCM)/Frequency Modulation (FM) PCM/FM and FM/FM are the two basic systems employed. PCM offers the advantage of many channels of accurate data readily convertible to processing. FM/FM offers the advantage of several channels of wide frequency response data such as is often required for measuring vibrations or A.C. electric fields. When combined on the same payload, as is often the case, the two systems complement each other and provide an excellent data collection system.

SOUNDING ROCKET LOW G RESEARCH

Suborbital rocket vehicles are being used for microgravity research in programs conducted by the United States and the European community. Most of this activity has been directed toward materials processing studies. A summary of sounding rocket low g research activities which have been conducted since the mid-seventies is included in Table II.

Table II. Sounding Rocket Low G Research Activities

- NASA SPAR PROGRAM (1975 - 1983) WSER
  - BLACK BRANT/NIKE-BLACK BRANT - 1-2 PER YEAR (10 FLIGHTS)
  - 6-5 MIN. LOW GRAVITY PERIOD

- TEXAS GERMAN MINISTRY FOR RESEARCH & DEVELOPMENT, ESA (1974 -) KSRANGE
  - KYLAX LANCING-BLACK BRANT -1-4 PER YEAR (50 FLIGHTS)
  - 54 MIN. LOW GRAVITY PERIOD

- MASERKSWEDISH SPACE CORPORATION (1967 -) KSRANGE
  - TERRIER-BLACK BRANT - 1 PER YEAR (6 FLIGHTS)
  - 67 MIN. LOW GRAVITY TIME

- CONSORTIUM (NASA CCSD) (1968 -) WSER
  - IMPROVED TERRIER-BLACK BRANT - 1 PER YEAR (4 FLIGHTS)
  - 74 MIN. LOW GRAVITY TIME

- MAXUS/GERMANSWEDISH (1991 -) ETRANGE
  - CASTOR 48 - 1 PER YEAR (1 FLIGHT)
  - 1514 MIN. LOW GRAVITY TIME

- JOUSTUGAR (NASA CCGS) (1991 -) ETR
  - MODIFIED CASTOR 48 - 1 PER YEAR (1 FLIGHT)
  - 1514 MIN. LOW GRAVITY TIME

The first program of this kind was the NASA Space Processing Applications Rocket (SPAR) program. A total of 10 missions were launched, beginning in 1975 and continuing until 1983. The first five launches in this program utilized single-stage Black Brant V launch vehicles; the last five utilized Nike-boosted Black Brant V vehicles which allowed additional experiment weight and microgravity time. The SPAR experiment development was managed at NASA's Marshall Space Flight Center (MSFC), and the payload integration support and launch services was provided by the NASA Sounding Rocket Program at Goddard Space Flight Center (GSFC). A suborbital rocket payload, free-falling in space, with very low angular rates provides a near zero gravity environment. In order to achieve a very low acceleration field for any period of time, the following conditions must exist:

- Absence of any external force gradients acting on the payload
- Absence of any payload body rates.
The first condition is met by the free-fall in space above the Earth's sensible atmosphere. The second condition can only be met by a positive means of controlling angular body rates at essentially zero. As a result, GSFC developed a rate control system (RCS) to meet the requirements of the SPAR program. This system was first flown on the initial SPAR mission, 21.032 NP, at White Sands Missile Range in December 1975. During this flight, the payload experienced a low g environment below $10^4$ g's for approximately 300 seconds. A typical mission profile for a SPAR mission is shown in Figure 6. A configuration sketch of a typical SPAR payload is depicted in Figure 7 for the final SPAR launch, mission 27.072 NP, launched on June 17, 1983. This payload contained three separate experiments and an experiment support module provided by MSFC. GSFC provided the recovery, vehicle telemetry, rate control, and payload separation systems. The European TEXUS and MASER programs are current suborbital flight activities. These flight programs have been conducted from the sounding rocket launch range in northern Sweden. These programs have been sponsored by the Swedish Space Corporation and the German Ministry for Research and Development, along with support by the European Space Agency. These two programs represent the most active suborbital microgravity research activities to date.

![Figure 6. Space Processing Applications Rocket (SPAR) Mission Profile](image)

![Figure 7. Space Processing Applications Rocket (SPAR) Payload Configuration](image)

Currently, two U.S. suborbital rocket programs, Consort and Jouit, are being conducted to provide in-flight investigations of materials processing in microgravity. These two programs are managed by the Consortium for Materials Development in Space (CMDMS) at the University of Alabama in Huntsville. These research activities are funded by grants from NASA's Office of Commercial Programs (OC) to the CMDMS. The CMDMS is 1 of 16 Centers for the Commercial Development in Space (CCDSs) established since 1985 by the OCP. All payloads are provided by the CCDSs in cooperation with their industrial partners. The CMDMS has been responsible for procuring the rockets, launch services, and payload integration services for the series. The intent is to encourage growth in the commercial launch industry in the United States. Thus, services provided by private industry have been sought whenever possible, as opposed to using university or government provided services. An exception to this has been launch ranges, because no commercial launch range presently exists in the United States.

The Consort program utilizes a Black Brant VC rocket motor, boosted by an improved Terrier booster (MK 70). This program is an outgrowth of the SPAR program and has utilized some of the SPAR payload hardware. The improved performance of the MK 70 booster provides an increase in microgravity time of about 1 minute over that provided by the European MASER flight system. Four Consort missions have been flown to date with the launch vehicle and associated launch services provided by the Space Services Division of EER Systems Corporation (formerly Space Services Inc. of America) and the

Experiments from several dozen investigators have been flown on the four Consort launches and a large number of individual experiments have been performed. The range of these experiments covers biological studies of the effects of low gravity on cellular transport, electroplating of metals and particulates and high temperature sintering of metal powders. A polyurethane foam ball was formed on Consort 1 and several other polymer investigations were performed. The last launch, Consort 4, was flown in November 1991. All Consort launches have utilized NASA Sounding Rocket Program facilities at the WSMR.

The Joust rocket will provide just over 13 minutes of low gravity time on a 30 minute flight. The rocket and launch services are provided by the Space Data Division of Orbital Sciences Corporation and payload integration is performed by Teledyne Brown Engineering. The rockets will be launched from the Eastern Test Range (ETR) in Florida and recovered in the Atlantic Ocean. The Joust program is significantly different from Consort but was planned to operate in parallel with complementary research objectives. The Joust flight system utilizes a much larger rocket vehicle (over twice the diameter as the Consort vehicle) which is guided throughout the burning phase of the rocket motor (modified Castor 4A with jet vane thrust vector control). Specific features of the Joust payload accommodations, as opposed to Consort, are:

- low gravity time is nominally 13-14 minutes (approximately twice Consort)
- payload volume is about 29 ft³ (approximately twice Consort)
- payloads are recovered at sea (Consort payloads are recovered on land)
- reduction of trajectory dispersion through the use of boost-phase spin-up is not required.
- ascent and reentry accelerations reach 20 and 40 g respectively (Consort levels are 10 and 25 g's respectively).

Joust 1 payload experiment standard mounting structures (longeron pairs) are configured so that experiments are interchangeable with Consort. Power distribution and control and experiment interfaces for signal transmission are also common between the two systems. Joust could accommodate two National Space Transportation System Get-Away-Special Payloads instead of the standard mounting structures.

The first Joust launch (Joust 1) was launched from the ETR in June 1991. A structural failure in the modified jet-vane control system caused this mission to fail; the future planning for the Joust program is dependent on the redesign effort currently underway by the Space Data Division. A different launch vehicle may be used in the Joust program for future launches.

SUMMARY

Suborbital rocket vehicles have proven to be very effective flight platforms for research conducted in the space environment. Although flight times are generally limited to minutes, the suborbital rocket vehicle is an effective method of achieving actual flight in space. These types of flight systems have been responsible for providing the means for milestone discoveries in space science and have also proven to be effective flight platforms for other types of space applications research. The NASA Sounding Rocket Program currently launches approximately 30 missions each year from locations around the world conducting low cost space science research. Although biological research using suborbital rockets has been somewhat limited, the low cost capability of obtaining several minutes of microgravity does offer potential in this area. This fact is borne out by the flight activities currently being conducted in several microgravity programs utilizing suborbital flight platforms.

REFERENCES


