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NASA Sounding Rockets User Handbook

Robert H. Burth, Philip G. Cathell, David B. Edwards, Ahmed H. Ghalib, John C. Gsell, Heath C. Hales, Herbert C. Haugh, and Brian R. Tibbetts

Peraton Inc., NASA Wallops Flight Facility, Wallops Island, VA

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National Aeronautics and
Space Administration

Goddard Space Flight Center
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NASA Sounding Rockets User Handbook

Sounding Rockets Program Office

Suborbital and Special Orbital Projects Directorate

NASA Goddard Space Flight Center

Wallops Flight Facility

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Preface

This Handbook describes the capabilities of the Sounding Rocket program, the design and technology applications used by that program, and the processes established to integrate the customer (principal investigator/program user/scientist/experimenter) into the mission team to ensure the highest probability of a successful project. Neither the United States Government nor any person acting on the behalf of the Unites States Government assumes any liability resulting from the use of information contained in this document or warrants that the use will be free from privately owned rights. The use of a company name does not imply approval or recommendation of the product to the exclusion of others that may also be suitable.

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Section 1: The NASA Sounding Rocket Program (NSRP)

This Handbook was written to assist NSRP customers in developing payloads that meet the requirements necessary to achieve mission-specific, scientific objectives, and to serve as a guideline in defining NSRP quality standards and ISO 9001-2015 requirements. For the purposes of this document, "customers" shall include principal investigators, program users, scientists, and experimenters.

1.1 The Program: 1959 –Present

The NSRP is a suborbital space flight program that primarily supports NASA-sponsored space and earth sciences research activities, other government agencies, and international sounding rocket groups and scientists. Since its inception in 1959, some 3,000 missions have flown with an overall science mission success rate in the previous twenty years exceeding ninety percent and launch vehicle success rate of over ninety-seven percent. The program is a low-cost, quick-response effort providing approximately twenty flight opportunities per year to scientific and technology demonstration investigations. Science investigations are involved in upper atmosphere, plasma physics, solar physics, planetary atmospheres, galactic astronomy, high energy astrophysics, and micro-gravity research. These rockets are launched from a variety of launch sites throughout the world.

In the mid-1980s, the NSRP 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, complexity, and range. NSRP flight systems are remarkably sophisticated spacecraft, capable of lofting 1,000- pound payloads to 280 kilometers and 250-pound payloads to 1,500 kilometers apogee.

NSRP customers consist primarily of university and government research groups; however, some research activities involve the commercial sector. The program has contributed major scientific findings and research papers to the world of suborbital space science, validated satellite tracking and instrumentation, and served as a proving ground for spaceship and space station components. Many new scientists have received training and developmental experience through NSRP internships and graduate study programs offered by participating educational institutions.

Systems and services provided to customers of the NSRP encompass the complete spectrum of support: mission management, payload design and development, launch vehicles, recovery systems, attitude control systems, payload testing and evaluation, analytical studies, launch range operations/coordination, tracking, data acquisition and data processing.
Customers are required to provide the scientific instruments/detectors for the payload, a comprehensive description of the support requested from NASA, and objective criteria that will used to determine the success or failure of the mission after all operations are complete.

The NSRP is conducted in compliance with ISO 9001-2015 but without the formal and expensive reliability and quality assurance employed in the larger and more costly orbital and deep space programs. This informal approach, combined with the extensive use of surplus military rocket motors, is instrumental in enabling the program to complete approximately 15-20 missions per year, using available resident WFF and WSMR resources. The NSROC program is required to maintain an 85% success rate (complete mission, vehicle, payload, and science) although the program goal is 100%.

Effective communications between the NASA project support team and the customer are vital to the success of individual sounding rocket missions and to the overall program. Project meetings, reviews, and the requisite post flight assessments of mission results by the customer are all feedback mechanisms which provide observation, comment and constructive criticism for problem solving and future programmatic improvements. The NASA approach to team-customer interaction is included in this Handbook to foster a better understanding of the thinking behind current program procedures. From design and development of the payload through launch and data processing, the customer is the essential source of information on how well the NSRP is working.

1.2 NASA Organizational Responsibilities

The NSRP is funded through the heliophysics division of the Science Mission Directorate (SMD).

1.2.1 Program Management

The NSRP at Goddard Space Flight Center (GSFC) falls under the Sounding Rockets Program Office (SRPO), Code 810, Suborbital and Special Orbital Projects Directorate (SSOPD), Code 800. The SRPO and SSPOD are located at Wallops Flight Facility (WFF) in Wallops Island, VA. The program is implemented under the NASA Sounding Rocket Operations Contract (NSROC) which is administered by the SRPO. NASA retains overall management of the NSRP including certain programmatic elements such as mission selection, funding, international agreements, grant administration, oversight and approval of the ground and flight safety process, and ownership of program assets.

1.2.2 Sounding Rocket Working Group (SRWG)

The SRWG is appointed by the Director of Goddard Space Flight Center to provide counsel and a forum for exchange of information on sounding rocket systems, operational support, and developments in science as they affect the program. The NASA Sounding Rocket Project Scientist, GSFC, chairs the group which consists of over ten members from the principal scientific disciplines served by sounding rockets. The NASA SRPO reports to this group in the areas of technical and management support.

1.3 Sounding Rocket Program Customer's Role

Once selected for flight participation, the customer becomes a member of the assigned mission team and is responsible for the preparation of the scientific experiment portion of the payload. Customers assist in establishing and conducting the operational program. Customers are responsible for defining the investigation, providing the necessary scientific instrumentation, completing timely processing and analysis of recovered data, and publishing the results. The customer is expected to participate in scientific and technical planning functions and formal reviews described later in this document.

1.3.1 Philosophy

The customer's role is critical to the success of the mission. NASA procedures are designed to support the customer and facilitate the best possible scientific return from the mission. Information regarding past experiences with the reliability of specific components and techniques is made available. While the assigned mission support team may recommend the use or avoidance of certain procedures and practices, final decisions on the internal details of the scientific instrumentation are normally left to the customer. Each payload is required to successfully complete a series of environmental tests which measure, test, and evaluate the ability of the scientific instrumentation to survive the flight environment. Determination of the ability of the scientific instrumentation to make the required measurements is normally made by the customer.

1.3.2 Payload and Instrumentation

Equipment provided as part of the program's customary mission support functions is described in Section 1.4 – Sounding Rocket Project Support Elements. The customer is normally responsible for developing and providing all other scientific instrumentation and related support equipment. They are also responsible for ensuring that it conforms to all required mechanical, thermal, and electrical interface specifications, meets all required safety standards, and can survive the predicted flight environment. Scientific instrumentation and related support equipment may be built within the customer's own laboratories or by associated contractors. To help ensure safe operation, the customer is required to furnish the data specified in Section 7 and Appendix E.

1.4 Sounding Rocket Project Support Elements

The NSROC contractor, provides the programmatic, technical, and business management functions necessary to plan, organize, implement, control, track, report, and deliver the goods and services required for implementation of the NSRP.

The NSROC contractor provides mission management for all assigned sounding rocket missions; this includes all planning and scheduling associated with individual mission requirements. Each mission is planned to meet science objectives and scheduled to avoid interference with the timely and cost-efficient completion of other ongoing missions. The Mission Database is a programmatic schedule for all missions and is maintained on the NSROC server.

At minimum, the Mission Database reflects the planned schedule for the following milestones:

- Launch Date
- Launch Time
- Integration Site/Date
- Mission Initiation Conference (MIC)
- Requirements Definition Meeting (RDM)
- Design Review (DR)
- Pre-Integration Review (PIR)
- Mission Readiness Review (MRR)
- Mission Close-out Report (MCR)

The NSROC contractor also provides services and supplies necessary for implementation of the individual missions and the overall program. As such, the contractor designs, fabricates, integrates, and performs flight qualification testing of suborbital payloads, provides launch vehicles, systems, and associated hardware, and provides various activities associated with subsequent mission launch operations. All relevant information is updated and maintained in the Mission Database.

1.4.1 Program-Provided Support Services

Customers of the Sounding Rocket Program are provided with a variety of support services. The assigned Mission Team is typically responsible for implementation of the mission utilizing their individual efforts and the extensive support capabilities provided by the program.

A typical Mission Team is composed of the customer, or their representative(s), applicable support staff, and additional team members provided by the support elements at WFF.

Team includes the following positions:

- Mission Manager
- Customer & Staff
- Mechanical Engineer
- Electrical Engineer
- Instrumentation Engineer
- GNC (Guidance, Navigation & Control) Engineer
- Flight Performance Engineer
- Mechanical Technician
- Electrical Technician
- GNC Technician
- Launch Vehicle Technician
- Flight Safety Representative
- Ground Safety Representative

The general categories of effort necessary for implementation of a mission include:

- Flight Mission Management
- Scientific Instrumentation *(typically provided by the customer)*
- Payload Analysis, Design, & Development
- Launch Vehicle and Payload Support Systems
- Payload Fabrication
- Payload Assembly/Integration, Testing, & Evaluation
- Launch & Flight Support Operations
- Post Flight Data Processing and Analysis
- Ground & Flight Safety

The following is a brief description, including organizational responsibility, of the individual support elements provided by the program for the typical mission. A detailed discussion of how sounding rocket flight projects are conducted with respect to a typical mission is included in Section 2 of this Handbook.

1.4.1.1 Flight Mission Management

NSROC management is responsible for selecting a Mission Manager (MM) for each mission. The MM has comprehensive, team leader responsibilities throughout the mission lifecycle and serves as the central point of contact for the customer. MM responsibilities include:

1. Developing an approach (technical, schedule, and cost effective), in conjunction with the assigned mission team, for meeting the mission requirements defined by the customer. This activity generally occurs in the period between the MIC and the RDM as described in Section 2 of this Handbook.
2. Coordinating and establishing a mutually acceptable date for holding, conducting, and documenting the RDM and all associated mission requirements in the subsequent Requirements Definition Meeting Memorandum.
3. Working with the customer and the NSROC Mission Team to design, develop, fabricate, integrate, test and flight quality the payload. The MM is responsible for coordinating, directing, and managing this effort, as well as establishing and maintaining the project schedule.
4. Directing and coordinating all Mission Team activities, including formal presentations at Design Reviews and Mission Readiness Reviews, and documenting the Mission Team's responses to any action items resulting from these reviews.
5. Coordinating and directing all field operations including preparation of the launch vehicle and conducting launch operations. The MM is the focal point for all field activities and has final, real time go/no-go authority for the mission, including launch vehicle status (concurrence for launch by range safety, SRPO, and the customer is required). The MM has no authority to override a customer or range safety decision to halt a launch, but may stop a launch when, in their opinion, a condition exists that jeopardizes the success of the flight.
6. Assessing the results of the launch to the extent possible and submitting required reports to the SRPO.

7. Coordinating and directing post flight operations necessary to complete all mission requirements.

1.4.1.2 Payload Analysis, Design, & Development

The following activities are associated with the analysis, design, and development function and are generally provided by the NSROC contractor:

- Electrical Engineering support for payloads, launch vehicles, and associated flight systems includes electrical systems (power supplies, event timing, wiring harnesses, monitoring subsystems) and instrumentation systems (telemetry subsystems).
- Mechanical Engineering support for payloads, launch vehicles, and associated flight systems includes all payload mechanical subsystems (overall layout and design, external skins, internal structures, bulkheads, component layouts, special mechanisms) and pyrotechnic devices (pin-pullers, bolt-cutters, and thrusters).
- GNC Engineering support for payloads and associated flight systems includes all boost guidance systems, navigation systems and attitude control systems. Support includes requirement review, auxiliary attitude sensor selection, implementation of external interfaces to the payload, pneumatic system propellant selection and thruster locations.
- Flight Performance analyses includes vehicle performance, nominal flight trajectories, trajectory dispersion, wind-compensation parameters, and impact aim-point considerations Support also includes vehicle static and dynamic stability evaluation (including aeroelastic effects, payload dynamics analyses, payload re-entry trajectory and recovery analyses ascent and re-entry aerodynamic heating analyses), post flight attitude solutions, and other suborbital analyses. These activities are performed during the pre-flight and post-flight analyses for each mission.

1.4.1.3 Launch Vehicle and Payload Support Systems

Launch vehicle and payload support systems are provided by the NSROC contractor and include rocket motors, pyrotechnics, and associated standard flight systems such as ejectable nose cones, payload/vehicle separation systems, upper stage ignition systems, and thrust termination systems. Activities associated with these systems include their inspection, modification, storage, shipment, assembly, launcher staging, umbilical rigging, and environmental control during launch operations. Other standard systems include payload recovery systems, special aerodynamic decelerators, payload attitude control and stabilization systems, and launch vehicle boost-guidance systems.

1.4.1.4 Payload Fabrication

Mechanical and electrical fabrication services are provided by the NSROC contractor. Electrical fabrication support includes specialized shops for electrical wiring assembly, printed circuit board fabrication, and electrical instrumentation development. The mechanical fabrication support includes the machine shop, welding shop, plastics and composite materials shop, sheet metal shop, and mechanical instrumentation shop.

1.4.1.5 Payload Assembly/Integration, Testing, & Evaluation

The development of a mission progresses from the fabrication and assembly of flight hardware, through the addition of customer-provided instrumentation and standard support systems, to a fully integrated payload. The payload then proceeds through the testing and evaluation process which involves the entire Mission Team (engineering personnel, technical support personnel, and the customer who has the technical knowledge of, and responsibility for, their instrumentation) and the laboratory support personnel who operate the various facilities involved in the processes. These facilities include payload assembly shops, telemetry ground stations, and the environmental testing lab. These processes include physical properties measurement; magnetic calibration; and vibration, shock, structural loads, spin-deployment, dynamic balancing, and vacuum testing. All these services are generally provided to the customer by the NSROC contractor.

1.4.1.6 Launch and Flight Support Operations

A critical element of conducting the NASA Sounding Rocket Program involves performing launch operations from various locations worldwide. Several of these launch sites are existing, full-time launch ranges. Mobile sites can also be established at remote locations which satisfy science requirements, such as specific observations (solar eclipses, supernova) and operations in specific areas (auroral zones, equatorial zones, Southern Hemisphere).

The following are brief descriptions of the major applicable elements involved in supporting sounding rocket flight operations:

The SRPO has an agreement with the NAVY at White Sands Missile Range to provide services for conducting launch operations from that location. The SRPO directs the NAVY to coordinate the provision of these services from the various service provider organizations and to support the specific requirements of each mission.

The SRPO has a contract with the University of Alaska for the maintenance and operation of the Poker Flat Research Range. This mechanism provides support for launch operations conducted from this high latitude location. Additional support for tracking and data acquisition services is provided through the NASA remote range services contract.

The SRPO also uses inter-governmental and international agreements necessary for the provision of launch operational support for mobile campaigns such as from the Marshall Islands and Puerto Rico; and from established foreign ranges such as Esrange, Sweden and Andøya, Norway.

The Range and Mission Management Office (RMMO), Code 840, is responsible for planning and directing the support necessary to meet the objectives of projects conducted on the WFF range and for mobile campaigns. The implementation of mobile campaigns for sounding rockets involves the support of several organizational elements within SSPOD. Additional support may also be provided by the ETD (Engineering Technology Directorate).

The RMMO schedules and directs flight test activities, provides test data packages to users, and coordinates range operations with various outside organizations for operations conducted from WFF and for mobile campaigns. When conducting an operation of sufficient magnitude at other ranges, SRPO assigns a "Campaign Manager." This individual has overall responsibility for managing the campaign. The Campaign Manager works closely with the Mission Manager(s), range personnel, safety, partner organizations, and foreign government or commercial organizations establishing the required launch support facilities, coordinating launch operations support, and deconflicting resource conflicts.

The range from which the operations are being conducted provides launch pads, launchers, blockhouse systems, controls, and consoles. Mechanical and electrical/electronic ground support equipment; flight support instrumentation such as search, tracking, and instrumentation radars; telemetry receiving and data recording stations; television and photographic tracking cameras; special purpose photo-optical equipment; surveillance and recovery operations aircraft; and facilities for payload preparation and check out are provided as part of the range services.

The NSROC contractor is generally responsible for conducting actual launch operations as well as all functions relating to the preparation of the launch vehicle and payload leading up to that event.

1.4.1.7 Post-Flight Data Processing and Analysis

The NSROC contractor is generally responsible for providing post flight processing and analysis of raw scientific data recovered from sounding rocket missions. This data is provided to the customer in the format specified at the RDM. Section 9 has additional information on available data processing and analysis support and procedures for obtaining that support.

1.4.1.8 Ground and Flight Safety

All work performed in support of the Sounding Rocket Program (SRP) is done in conformance with all WFF, GSFC, NASA, and other government regulations, requirements, and statutes. Ground and flight safety data requirements for sounding rocket vehicles and payloads are contained in the Range Safety Manual for Goddard Space Flight Center (GSFC)/Wallops Flight Facility (WFF), (RSM-2022). This manual contains specific design requirements for flight systems and describes data that must be supplied to the Wallops Flight Facility Safety Office (Code 390) to obtain NASA safety approval for launch systems. Institutional safety requirements are contained in NPG 8715.3, NASA Safety Manual. The NSROC contractor is responsible for meeting these requirements as well as any additional safety requirements of other domestic or foreign ranges utilized during implementation of the SRP. Further, the NSROC contractor is responsible for maintaining awareness of all changes and modifications to statutes, regulations, and procedures impacting ground and flight safety.

The NASA Safety Office is responsible for oversight and approval of all ground and flight safety processes. As such, the NASA Safety Office provides all necessary Safety Plans based on the data and analyses provided by the NSROC contractor. The NSROC contractor is contractually required to provide all data, analysis, and information necessary for the development of these, and any other, required plans. The NASA Safety Office plans and coordinates safety aspects of launch operations, establishes range clearance and range safety limitations, and reviews and approves hazardous assembly and pad procedures. The NSROC contractor is responsible for implementing all the requirements of the Ground and Flight Safety Plans for NSROC-supported missions.

For hazardous operations (other than pad operations), the NSROC contractor is responsible for the following:

Providing Operational Safety Specialist(s) whose primary responsibility is safety oversight. This person or persons interfaces directly with the NASA Safety Office oversight authority in resolving real-time safety concerns.

Implementing all general operation (crane operation, forklift operation, etc.), personnel safety (explosives and ordnance, pressure vessels and systems, chemical, radiation, etc.) and facilities (equipment calibration, maintenance of safety devices, access control) requirements.

A detailed discussion of sounding rocket safety considerations and policies is provided in Section 7 of this Handbook; additional NSRP support capabilities are addressed in Section 2.

Section 2: The Sounding Rocket Mission Lifecycle

This Section describes the process NASA uses in conducting a sounding rocket flight project (mission) using the management and support elements at Goddard Space Flight Center's Wallops Flight Facility (WFF) discussed in Section 1.4.

The various phases and milestone reviews of a typical mission are outlined in the sections below and summarized in Figure 2-1.

2.1 The Mission Initiation Conference (MIC)

Flight projects must be approved by the appropriate science discipline chief at NASA Headquarters. Once this approval has been obtained, the customer will be contacted by the SRPO to establish a mutually acceptable date for a MIC between the customer and WFF personnel. The purpose of this first meeting in the mission lifecycle is for the customer to present a MIC Data Package which details requirements and specifies the support necessary for the mission.

The MIC is chaired and documented by the SRPO. Attendees include the customer, appropriate WFF supervisory and engineering personnel, NSROC supervisory, engineering, and technical personnel, as well as the assigned payload team. A well-conducted and documented MIC will result in a strong foundation on which to begin the mission. The MIC provides the basis from which all requirements for the mission are established. These include the following:

2.1.1 Project Schedule

The customer should be prepared to answer specific and detailed questions regarding the scheduling of major mission milestones such as launch window date and time.

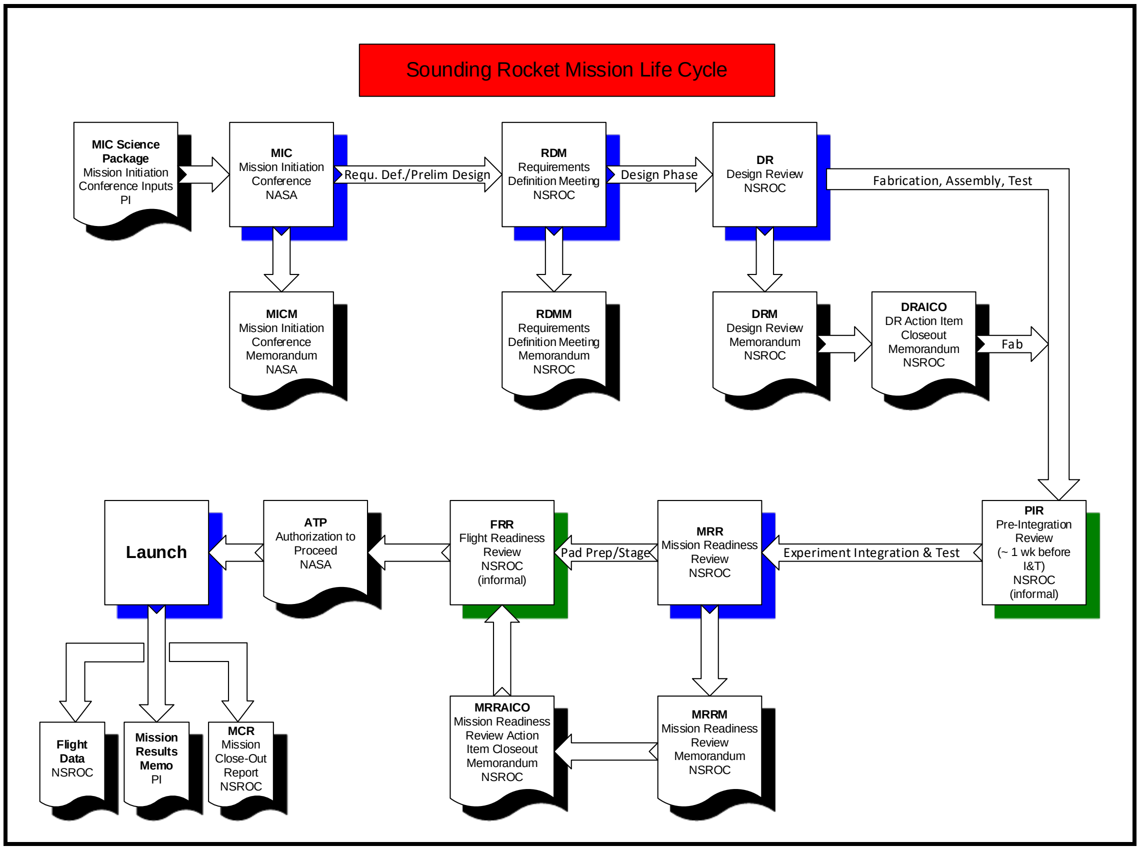


Figure 2.1: Typical Sounding Rocket Mission Life Cycle

2.1.2 Mechanical Devices and Structural Elements

The requirements for mechanical work will be discussed in as much detail as possible. Mechanical items of interest include deployable nose cones, doors (access, deployable or retractable), extendible booms, antennas, sensors, and any unique structural items or payload skin requirements. Any temperature limitations, vacuum requirements, or novel mechanical devices/systems should be discussed, including land and water recovery requirements.

2.1.3 Flight Performance

All payload flight trajectory/timeline requirements such as apogee, altitude, or time-above-altitude should be reviewed and requirements for payload dynamics (spin rate and/or coning limits) included. Some payload designs involve long, flexible booms while others involve tethers and sub-payloads; dynamic requirements for this type of payload should be presented.

The best estimate of payload weight should be determined for the MIC, being careful not to eliminate any significant payload components. The flight performance characteristics of NASA sounding rocket launch vehicles are presented in Section 3 and Appendix A.

2.1.4 Instrumentation

Experiment data requirements should be presented at the MIC in sufficient detail to allow definition of the telemetry system for the payload. Experiment programming requirements (on-board timers, uplink commands, or special monitoring) should be discussed. A detailed description of standard instrumentation systems is included in Section 5 of this Handbook.

2.1.5 Attitude Control

Attitude knowledge, control and stabilization of space science payloads are key elements in many science experiments. Attitude system requirements should be fully discussed to determine the type of Attitude Control System (ACS) required. The nature of celestial targets should be defined, and any attitude maneuver sequences employed. Pointing accuracy and stability (jitter) should be specified. Known payload launch constraints are presented at the MIC. The types and capabilities of sounding rocket attitude control systems are presented in Section 5.

2.1.6 Navigation

Requirements frequently include detailed definitive knowledge of space/time during flight. Applicable requirements should be addressed in the MIC.

2.1.7 Data Reduction

The customer can obtain assistance in data processing and analysis from WFF. Specific data reduction requirements should be discussed at the MIC. A description of WFF capabilities for data processing and analysis, and guidance on requesting support, is provided in Section 9.

2.1.8 Testing

SRP testing policies are detailed in Section 6. In general, all flight payloads must be tested in accordance with the testing specifications. Any special testing concerns or requirements should be discussed at the MIC.

2.1.9 Foreign Nationals

Sounding Rockets are considered Significant Military Equipment (SME) and are listed on the ITAR US Munitions List (USML). If foreign nationals are involved with experiment design and testing or field operations, the MM must be notified at the MIC to allow enough time to process paperwork required for a Technical Assistance Agreement (TAA). This allows NSROC personnel to interact directly with non-US citizens to work design issues, conduct payload integration and complete field operations.

2.2 Requirements Definition Phase

Following the MIC, the NSROC payload team works with the experiment team to develop a mission design concept based on requirements provided at the MIC. The goal is to complete this phase in forty-five days; however, for complex missions, much more collaboration with the experiment team may be required before a reasonable mission concept is designed. For a complex mission this phase may involve significant preliminary design effort to verify requirements can be met. If requirements cannot be met within reasonable cost and time, adjustments may have to be made.

2.3 The Requirements Definition Meeting (RDM)

Initiated by the NSROC contractor, the RDM includes representatives from NASA and the customer. All information necessary to define and demonstrate the feasibility of the mission and how the mission requirements will be achieved are presented by the NSROC payload team. The experiment team attends the meeting to verify the mission requirements have been understood and are being met.

A Requirements Definition Meeting Memorandum (RDMM) is documented by the NSROC contractor and provided to NASA within 5 days of the RDM. It serves as the contractor's task plan and documents mission technical requirements, the approach to satisfying those requirements, schedule, and cost information.

2.4 Design Phase

After the RDM the NSROC payload team typically holds regularly scheduled meetings with the experiment team to finalize and document all payload design details. Mechanical and electrical interface requirements are finalized. Detailed mechanical prints and electrical schematics are created as well as a mission timeline. If attitude control is required, a detailed control plan is devised. A test plan to qualify the complete payload for flight operations is created. Often, new designs are proven by building and testing non-flight hardware. Once this process is complete the Design Review is held.

2.5 Design Review (DR)

The objective of the DR is for the payload team to present a comprehensive description of all aspects of the payload/vehicle design to maximize potential for mission success.

The MM, in conjunction with the PI, schedules the Design Review and coordinates the Project Team's preparedness.

The NSROC contractor establishes a Design Review Panel to review all aspects of the mission, vehicle, design, test plan, and integration activities. The Panel consists of NSROC personnel who are not directly involved with the mission but who have established expertise in the areas of technical support required for mission success, including the following: Operations, Flight Performance, Mechanical Systems, Electrical Systems, Instrumentation Systems, Guidance, Navigation and Control Systems, Launch Vehicle Systems, Ground Safety (NASA), and Flight Safety (NASA).
During the DR, the Mission Team formally and systematically presents all information necessary to demonstrate that the proposed design and mission approach will meet all mission and safety requirements. The customer should be prepared to discuss all details of the scientific instrument design and interface with the support systems.

After completion of the meeting, the panel reconvenes to discuss the results, and document action items that are provided to the MM for disposition. The Review Panel Chairman generates a Design Review Memorandum (DRM) which summarizes the meeting and documents all assigned action items. The DRM documents that the DR package and presentation demonstrate the proposed design and mission approach can meet the mission success criteria once action items are addressed.

The MM is responsible for directing the Mission Team in responding to DR action items. This effort is formally documented with a memorandum to the Design Review Panel Chairman.

The panel reviews all responses and either concurs or asks for additional information and clarification. Once all responses are deemed acceptable the process is officially closed out with a memo from the Panel Chairman to the SRPO. Fabrication may now begin. Some standard parts and systems, including those that didn't generate actions at the Design Review, may begin their fabrication immediately after the meeting; or, in some cases, even earlier.

2.6 Payload Fabrication and Pre-Integration Testing Phase

Payloads are assembled with a combination of custom fabricated mechanical and electrical parts and assemblies from the NSROC shops, as well as a variety of purchased parts and assemblies. Mechanical hardware is assembled and fit-checked prior to integration with scientific instrumentation provided by the customer. Electrical and telemetry instrumentation wiring, and components are assembled and tested prior to integration with the customer's electrical/data systems to facilitate a smooth, trouble-free integration effort. Special pre-integration design qualification tests are often performed for new separation/ejection/ deployment mechanisms, vacuum doors, and other devices. These special tests are in addition to the total payload post-integration testing that must be successfully completed before flight.

All NSROC provided sub-systems (such as telemetry, recovery, ACS, and motor ignition systems) are connected to ensure they function properly prior to being connected to experiment systems.

Integration and testing of new payloads (except as described below) is usually conducted at WFF. General information concerning the integration and testing laboratories at WFF is presented in Section 10; Section 6 describes specific testing policies. Integration and testing of SPARCS payloads is performed at WSMR as these systems require special equipment that is resident only at that location. Section 6 provides a description of the facilities available for SPARCS payloads at WSMR.

2.7 Pre-Integration Review (PIR)

A PIR by the mission team occurs prior to payload Integration and Test. The purpose of this meeting is to assess the Mission Team's readiness to support payload integration activities prior to authorizing travel by the customer or their staff. This serves to ensure that the customer is not inconvenienced by having to wait while WFF personnel complete preparation activities for support systems necessary for payload integration and vice versa.

2.8 Integration and Testing (I&T) Phase

I&T is comprised of payload integration, acceptance testing, and final checkout. When the final checkout indicates that all the subsystems operate as planned and are mutually compatible, the payload can be shipped to the launch site with confidence that only minor adjustments or calibrations will be necessary in the field.

I&T (except as described below) is conducted at WFF. General information concerning the integration and testing laboratories at WFF is presented in Section 10; Section 6 describes specific testing policies. I&T of SPARCS payloads is performed at WSMR as these systems require special equipment that is resident only at that location. Also, integration of previously flown White Sands missions is performed at White Sands. Section 6 provides a description of the test facilities available at WSMR.

2.8.1 Payload Integration

Payload Integration is the first-time assembly of all the NSROC provided parts and pieces with experiment hardware into the launch configuration. All aspects of the design and operation are checked including mechanical fit and operation, telemetry and electrical systems operation, and systems compatibility. Pre-testing sequence tests are performed to insure the event-programming system functions properly.

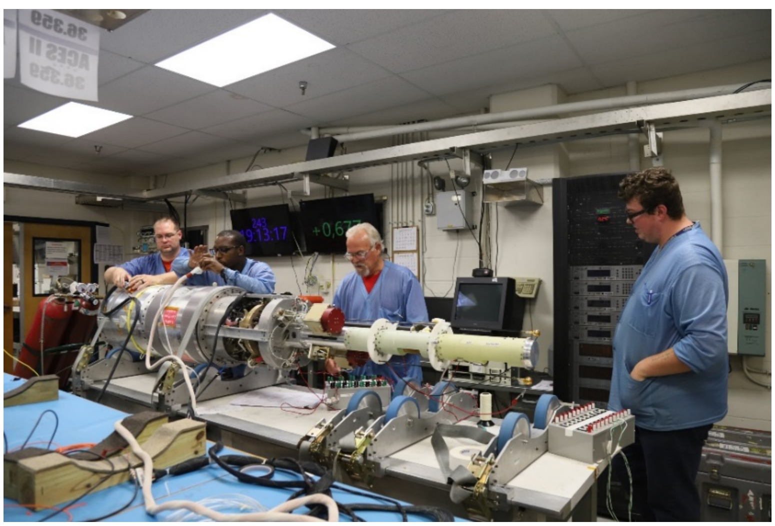


Figure 2.2: Payload Integration in Ground Station #2 at WFF

2.8.2 Acceptance Testing

After successfully passing the payload integration checks, the assembled payload is taken to the Test and Evaluation (T&E) Laboratory where it is subjected to acceptance tests such as vibration, bend, and operational spin as well as mass property measurements. Acceptance tests simulate the conditions the payload is likely to encounter in flight. Payload sub-systems, that are required to operate in flight, are functional during the acceptance tests. Every system must demonstrate the ability to survive flight conditions through completion of its intended function.

When special conditions or circumstances occur which warrant an exception to standard testing policies, the customer may submit a written request for waiver to the MM. The reason for the request, possible results if failure should occur during flight, and any other pertinent details should be stated in this request. Although waivers are infrequently required, they may be granted by NSROC management after consultation with all involved parties.

Figure 2.3: 46.025 UE Undergoing Acceptance Testing in the Spin-Deploy Bay

2.8.3 Final Checkout

After the payload has completed acceptance testing, it receives a final checkout which is in essence, of the payload integration checks described earlier. This process looks for defects in workmanship or other anomalies that may have been discovered through the acceptance testing process.

2.9 Mission Readiness Review (MRR)

The MRR is a formal review to determine if the mission is ready to proceed with launch operations with a high probability of meeting mission success criteria. It generally takes place at WFF prior to hardware shipment to the field but can take place in WSMR after shipping and travel in the case of a mission that performs I&T at WSMR.

The MRR generally follows the same basic process as the DR but instead of focusing on design, the focus is on results of the I & T process. A Mission Readiness Review Panel, composed of chairman and other technically qualified personnel, not directly involved with the flight project, is established by NSROC Management. Information presented at the MRR must demonstrate that all environmental testing and flight qualifications have been successfully completed, all required GSE, and range support assets and services have been identified and scheduled, and that arrangements for the provision of all required GSE and range support assets and services have been completed. Problems encountered during integration and testing, including the adequacy of any modifications or repairs are reviewed. Information regarding procedures is provided; and a final FRP, which includes the detailed field operations plan and schedule, is included in the MRR documentation. The mission schedule is updated and any changes in the design, test plan, procedures, or mission approach that have occurred since the DR are documented and justified.

The customer should be prepared to discuss all aspects of experiment hardware status, test results, and mission success criteria.

Should action items result from the MRR process, it is highly desirable that they be dispositioned prior to shipping payload hardware or travel of the Mission Team to the field (except in the case of I&T performed at WSMR). NASA, NSROC, and customer representatives may attend the MRR and assign action items as necessary. One major difference between the DR and MRR action items is that if the MRR action items are not addressed to NASA's satisfaction, NASA has the authority to halt launch operations until this requirement is met. As a final go/no go checkpoint, the SRPO issues written authorization to the NSROC contractor to proceed with launch operations

2.10 Flight Readiness Review (FRR)

The FRR takes place once the payload is staged on the rail, umbilicals are rigged, environmental boxes are built, and flight preparations are complete. The NSROC payload team, experiment team, and NSROC management meet to verify all MRR actions are closed, review any issues that have developed since the MRR, and generally verify that the mission is ready to launch. Upon completion of the meeting, NSROC management sends a letter to SRPO stating the mission is ready for launch. As a final go/no go checkpoint, the SRPO issues written authorization to the NSROC contractor to proceed with launch operations after they are satisfied all requirements have been met.

2.11 Launch Operations Phase

Sounding rocket launch operations are conducted from various launch sites worldwide. These vary from well-established launch ranges to barren temporary facilities outfitted with mobile equipment. A detailed discussion of launch operations at various domestic, foreign, and mobile launch sites is included in Section 8 and Appendix B. Section 10 has information regarding the range at WFF.

The Mission Manager is responsible for coordinating all launch support requirements between the range and experiment team to ensure successful data collection. If required, recovery operations are arranged.

Immediately following a launch, the MM is responsible for providing a preliminary assessment of the results. The customer should assess the science results and report the overall status to the MM as soon as possible. In some cases, the payload must be recovered and returned for analyses before final science results can be determined. In the case of a flight failure, all recovered hardware is impounded by the NSROC contractor for inspection by cognizant personnel in a failure investigation.

Most established launch ranges conduct a post-flight meeting to review mission results. This conference gives the customer an opportunity to provide compliments or complaints concerning the field services provided; the input provides a "lessons learned" resource for future NSROC and range support service improvements.

2.12 Mission Closeout Phase

A sounding rocket mission is not considered complete until all data requirements and post-flight reporting requirements have been satisfied. The customer's data requirements should be documented in the RDMM. Any changes that occur in these requirements during the progress of the mission should be documented in the DRM or MRRM. The MM is responsible for ensuring that all data requirements are satisfied. Special data processing and/or analysis support can be made available. A discussion of available data processing and analysis capabilities is provided in Section 9.

The customer is requested to provide a written response indicating the level of success or failure of the mission and any recommendations for improvements that the customer may suggest as soon as the flight data has been reviewed. NASA officially classifies the mission as a success or failure based on this input.

NASA sounding rockets have maintained a success rate exceeding ninety percent in the previous twenty years. A successful flight is defined as one that meets the minimum success criteria. When the minimum success criteria for any given flight are not met, the flight is officially considered a failure. All sounding rocket flight failures are formally investigated to identify the cause(s) of the failure so that appropriate corrective action(s) can be taken. If the failure is caused by a problem with scientific instrumentation or associated hardware provided by the customer, the customer is responsible for determining the cause(s) and taking corrective action(s) prior to re-flight. Technical assistance and consultation can be provided to the customer as necessary. Upon completion of the failure investigation, the customer is requested to provide the findings, conclusions, and corrective action(s) to NASA through the Chief, SRPO.

The NSROC contractor is responsible for identifying anomalies, failures, and systemic problems with flight vehicle systems, payload systems, GSE, and analytical methods employed in the support of the NSRP. All direct and contributing causes of anomalies, failures, and systemic problems are investigated, resolved, and fully documented with corrective action being identified and implemented in a timely manner. NASA reserves the right to observe and/or participate in contractor-staffed anomaly and failure investigations and to conduct independent investigations.

An AIB is composed of individuals selected for their expertise in areas related to the failure. The customer (or representative) may be requested to serve on an AIB. The team will, in some cases, issue preliminary findings and recommendations regarding pending missions that may be affected by similar problems. Launch operations for these missions may be postponed until a resolution of the problem has been achieved. A formal, final investigation report is issued as soon as possible following completion of the investigation.

In some cases, problems occur during flight with payload sub-systems that result in abnormal payload operations but do not result in a mission failure. Likewise, the launch vehicle can exhibit abnormal performance characteristics, but still provide an adequate flight trajectory for satisfying the minimum requirements for scientific success. In these cases, the overall mission is deemed a success, and the abnormal occurrences are considered in-flight anomalies. In-flight anomalies that lead to a mission failure are always considered major occurrences that require formal investigation. For major anomalies (generally those which, should they recur, have the potential to jeopardize the success of future missions), an Anomaly Investigation Board is appointed.

The Mission Closeout Report (MCR) is the final official document in the mission lifecycle. It fully documents the mission's success or failure and includes a detailed assessment of the performance of all sub-systems and comparison to pre-flight predictions. Once NSROC submits this document to SRPO, the mission is complete.

Section 3: Sounding Rocket Launch Vehicles and Performance

A family of standard sounding rocket launch vehicles are 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 exclusive use in NASA programs. These vehicles can accommodate a wide variety of payload configurations and providing an extensive performance envelope.

3.1 NASA Mission Designation System

NASA sounding rocket launch vehicles are identified by a numbering system. The first two digits of the flight mission number identify the type of launch vehicle used. The remaining three digits indicate the mission number for that launch vehicle type. The first and second letters following the digits identify the type of organization sponsoring the mission and the scientific discipline of the experiment, respectively. Table 3.1-1 lists the specific vehicle numbering system as well as the agency and experiment type. Table 3.1-1 also has an example flight mission number to demonstrate the naming convention. In addition to the mission number, missions are colloquially referred to by the last name of the PI or the acronym of the experiment.

3.2 NASA Sounding Rockets

There are several operational launch vehicles in the NASA Sounding Rocket Program. All NASA sounding rocket launch vehicles use solid propellant propulsion systems arranged in single to multi-stage configurations (up to four stages). Extensive use is made of surplus military motors in most of the vehicle configurations. All vehicles are unguided except those which use the S-19 Boost Guidance System (White Sands Missile Range only). During flight, all launch vehicles are imparted with a spinning motion to reduce dispersion of the flight trajectory due to vehicle misalignments. The spinning motion is created by angling the fins at a slight cant angle relative to the vehicle's direction of motion. Some missions utilize spin motors for additional rotation for the same purpose. The operational launch vehicles and their NASA designations are presented in Figure 3.2-1.

3.2.1 Performance Characteristics

Performance characteristics for apogee, altitude, and weight capability and flight time above 100 kilometers for NASA sounding rocket vehicles are included in Figure 3.2.1-1. This data is presented for a sea level launch using a launch elevation angle of 85 degrees. Appendix A has detailed descriptions and flight performance characteristics for these vehicles.

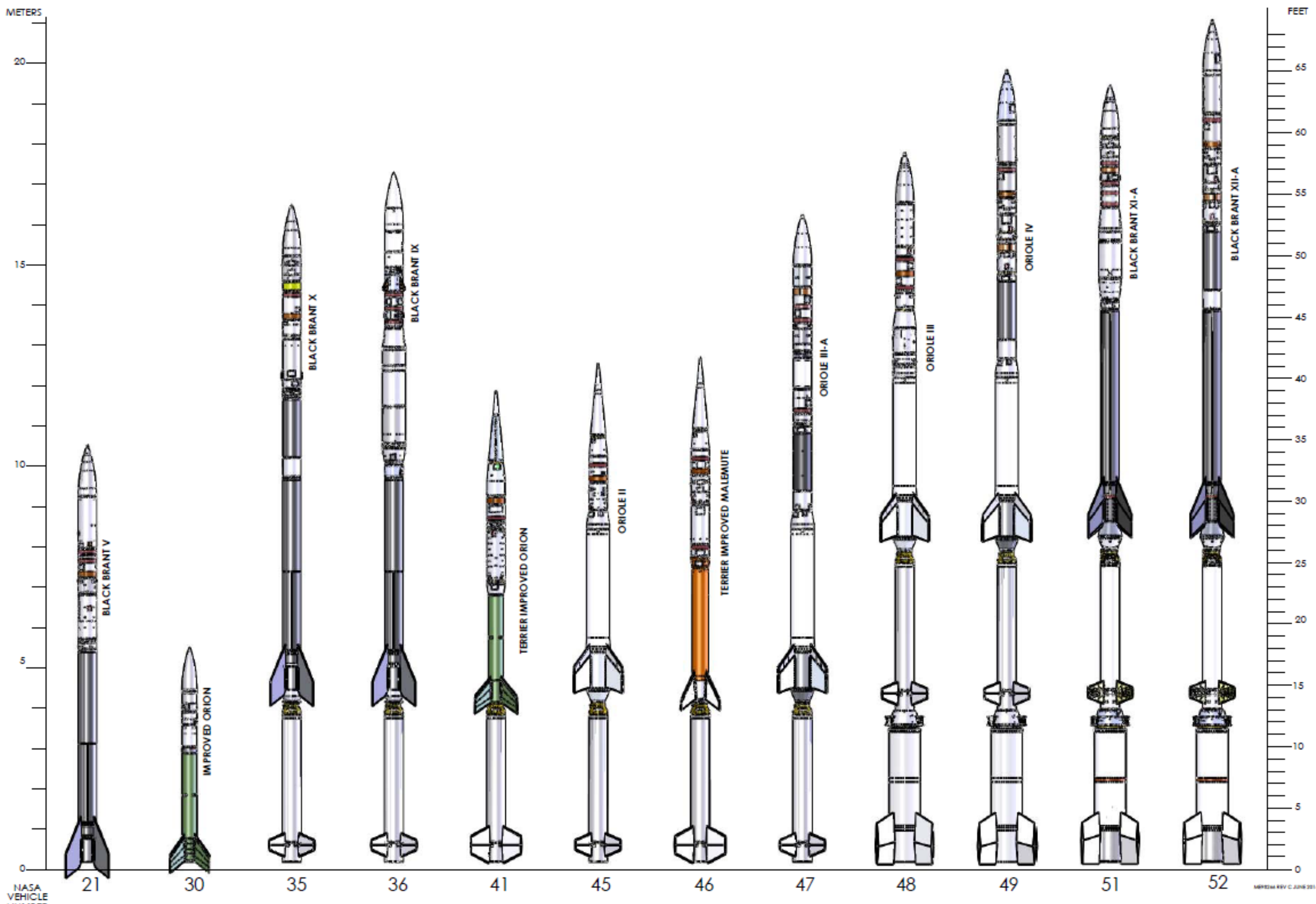


Figure 3.1: NASA Sounding Rocket Launch Vehicles

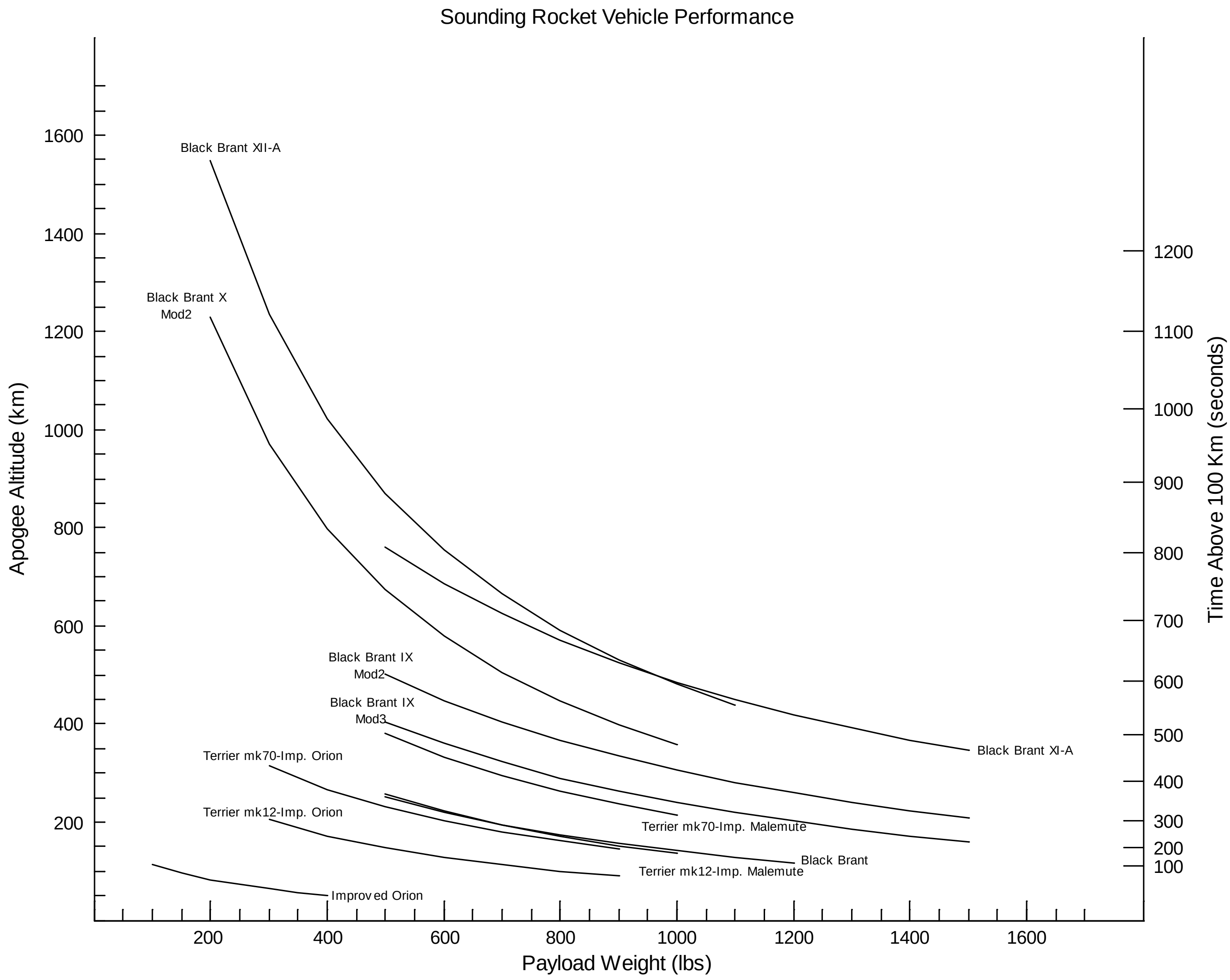


Figure 3.2: NASA Sounding Rocket Capabilities

Table 3.1-1 Sounding Rocket Agency, Vehicle and Experiment Identification

NASA Vehicle Numbers: (12) Special /Development Test Vehicles (21) Black Brant (Single Stage) (30) Improved Orion (Single Stage) (35) Black Brant X (Terrier-Black Brant-Nihka) (36) Black Brant IX (Terrier-Black Brant) (41) Terrier-Improved Orion (45) Oriole II (Terrier- Oriole) (46) Terrier-Improved Malemute (47) Oriole-III A (Terrier-Oriole-Nihka) (48) Oriole-III (Talos-Terrier-Oriole) (49) Oriole-IV (Talos-Terrier-Oriole-Nihka) (51) Black Brant XI-A (Talos-Terrier-Black Brant) (52) Black Brant XII-A (Talos-Terrier-Black Brant-Nihka)	**Agency** G - Goddard Space Flight Center (Other than WFF) W - Wallops Flight Facility N - Other NASA Centers U - College or University D - Department of Defense A - Other U.S. Government Agency C - Industrial Corporations I - International
	Type of Experiment B – Laboratory Astrophysics E - Geospace Sciences G - UV/Optical Astrophysics H - High Energy Astrophysics L - Solar System Exploration P - Special Projects S - Solar & Heliospheric Sciences T - Test and Support M - Microgravity Research O - Student Outreach R - Reimbursable

Example of Mission Number: 36.035UE			
36	.035	U	E
Black Brant IX	35th Assigned Mission	College or University	Geospace Sciences

3.3 Boost Guidance System (BGS)

The S-19L is a navigation, guidance, and control system designed to reduce the impact dispersion of rockets launched from the smaller ranges such as White Sands Missile Range. The system is designed and maintained by Beyond Gravity (formerly RUAG), and it is considered a safety-critical component of any sounding rocket mission that uses it. Missions that land in the ocean from the larger missile ranges such as Wallops Flight Facility or Andoya Missile Range typically do not use a boost guidance system.

The S-19L is composed of a strap-down LN-200 IMU, a flight computer with GNC software, and 4 canards actuated by 2 electric servo motors assisted by high pressure gas from a pneumatic system. Each servo turns a shaft connected to a pair of canards. The system has no active roll control since it operates while the rocket is spinning at ~ 4Hz.

Just before launch, the navigation algorithm performs gyro-compassing to initialize the attitude solution without requiring external information. The guidance system is designed to regulate the pitch & yaw angles to their initial values (holding the launcher attitude). The autopilot converts the guidance commands in the non-rolling frame into canard deflection commands in the rolling frame.

After 18 seconds of control, pyrotechnics are activated to physically decouple the canards from the control system, so that they are effectively "free-floating in the wind" and no longer capable of exerting any aerodynamic moment on the rocket. The rocket becomes unguided at this point and remains essentially unguided until impact.

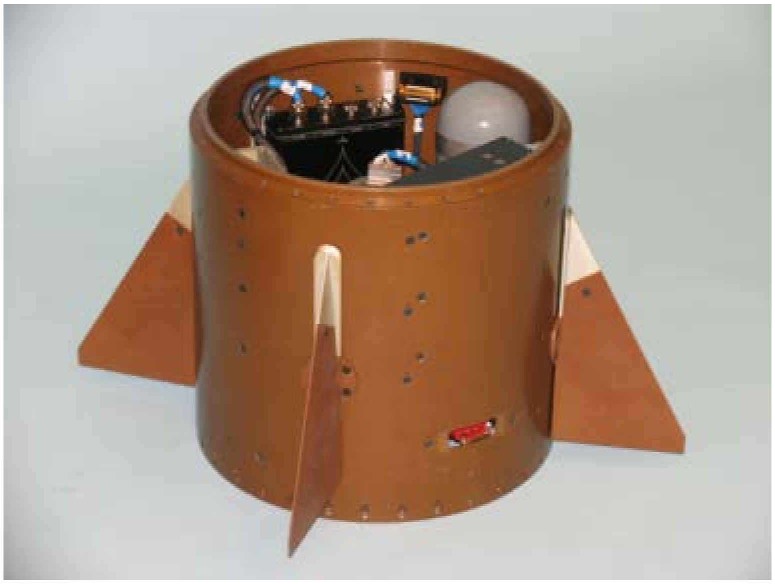


Figure 3.3: S-19 Boost Guidance System

3.3.1 Background & Capabilities

The S-19 started out in the 1970's as an analog system using mechanical gyros together with the same guidance law still in use today. It was upgraded in 1999 to incorporate accelerometers and digital gyros in a system called DMARS (digital attitude reference system). This new system, dubbed the DS-19, also used a different guidance scheme called "inertial impact point (IIP) guidance" which aimed the rocket at a small window in space and extended the control time beyond 18 sec to the entire atmospheric portion of the flight (~50 sec). Although a technically superior solution, range safety considerations and lack of an automated flight termination system at White Sands Missile Range preclude its use in the IIP mode. At White Sands, the DS-19 was restricted to the basic S-19 launch rail attitude hold guidance mode, and in this configuration, it was designated the S-19D. In 2006, the IMU was upgraded once more to the LN-200, and this system has flown as the S-19L ever since.

The S-19L has a 3-sigma impact dispersion of 7.5% of the apogee for both down-range and cross-range. This means that for a flight to 300 km altitude, the 2nd stage rocket and payload sections can be expected to land within 22.5 km of the nominal impact point. This is an improvement over unguided rockets by a factor of 5-10.

Beyond Space is working on a new version called the S-19E which reduces complexity by removing the pneumatic system entirely in favor of all electric servos.

Section 4: Sounding Rocket Payload Design Considerations

The sounding rocket payload must achieve the scientific objectives of the customer while functioning within the mechanical, electrical, and environmental parameters of a sounding rocket. Consequently, the customer and his support staff must work closely with the NSROC mission team to ensure that all mechanical and electrical design elements are fully integrated and proper interfaces between all payload subsystems are established.

4.1 Payload Design

Sounding rocket payloads are designed to accommodate diverse scientific objectives. Thus, payloads vary greatly in design characteristics. However, most payloads consist of the following systems:

- Scientific Instrumentation
- Mechanical Systems
- Electrical Systems
- Event Timing/Programming
- Pyrotechnic Devices
- Telemetry Systems
- Attitude Control System
- Recovery System
- Boost Guidance Systems

The payload may include sustainer ignition, separation, and de-spin systems. Generally, these functions are provided by standard modules that are designed to interface with a variety of standard sounding rocket launch vehicles.

It is accepted that flight-proven designs are likely to be more available and reliable than new designs. Ensure there are no existing designs that are adequate before a new design is undertaken.

Sounding rocket payloads must endure a hostile flight environment during the ascent phase of flight. NASA has extensive experience in and knowledge of the flight environment and other factors which influence payload design. This Section describes factors to be considered in payload design to help ensure a reliable, safe, productive, and cost-effective payload.

4.2 Flight Performance

The environment for sounding rockets may prove hostile to the mechanical, electrical, and aerodynamic functions of the payload. The controlled environment for payloads on earth changes abruptly at launch. Large variations in temperature, acceleration, atmospheric pressure, vibration, and other effects are encountered. The specific flight environment for any given flight demands consideration in the design and construction of successful payloads.

4.2.1 Mechanical Loads and Vibration

The longitudinal and lateral loads imparted due to rocket motor thrust, aerodynamics, winds, spin rates and abrupt changes in spin rate due to de-spin devices are major design considerations. Longitudinal acceleration levels depend on the specific type of launch vehicle used. 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 (cps). The effects of spin-induced loads should be considered when components are mounted off the spin-axis. Load factors exceeding 30 g's can be experienced by components mounted near the payload external skin depending on the diameter of payload and the spin rate. Most electronic devices utilize small, lightweight circuit boards and components. When soldering is performed properly with a conformal coating applied, problems caused by mechanical loads are rare.

Another environmental factor is the vibration induced by rocket motor burning and aerodynamic loading. The vibration environment depends on the type of launch vehicle as well as the mass and structural characteristics of the payload. Vibration testing is one of the key acceptance tests used to certify a payload for flight; all payloads must pass flight acceptance vibration tests. Poor mechanical designs (such as thin-walled structures) can induce excessive loads on components, such as sensitive electronics parts. As such, components should not be supported by their leads and should not be coincident with other components or structures. A detailed description of vibration testing policies and specifications are included in Section 6.

4.2.2 Thermal Considerations

Sounding rockets can reach hypersonic speeds while traveling through the earth's atmosphere. Surface heating due to these speeds is significant due to skin friction and by atmospheric heating when a payload re-enters the atmosphere from space. Even though payload exterior skin surfaces experience high temperatures due to ascent aerodynamic heating, the temperature of internal components does not vary greatly. Component temperature depends primarily on where and how components are mounted relative to the payload skin. Heating of electronic components due to operation over long periods of time (during preflight check-out, for example) can be more severe. Component heating is exacerbated if the component cannot effectively displace heat while in a vacuum. Component specific heat paths may be required to ensure overheating does not occur. Heat analyses can be performed as a part of the overall mission analysis for any given mission. Engineering personnel at WFF have accumulated significant, historical, thermal data by measuring the thermal environment of hundreds of sounding rocket flights If a particular component is sensitive to elevated temperatures, it may have to be insulated or isolated from heat sources.

4.2.3 Vacuum and Out-Gassing

When rocket payloads rapidly ascend in the atmosphere, ambient atmospheric pressure drops quickly and approaches zero. Payloads are designed to vent internal air during the ascent. 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 is subjected to vacuum, be aware of good vacuum design practices.
The most common undesirable effects of vacuum are reduced heat flux and corona; both are relatively easy to overcome if they are identified early in the mission lifecycle. Another design consideration which can degrade data is material out-gassing. WFF can advise on suitable materials, techniques, and standards to minimize out-gassing. Materials such as lacing, insulation and adhesive tapes are often overlooked when considering out-gassing materials.

In many cases, portions of a payload require hermetically sealed joints or doors to maintain sealed conditions either under pressure or in a vacuum. WFF has designed and developed numerous types of hardware for sealing purposes.

4.2.4 Aerodynamic Design Factors

A design that involves any protuberance or change in the rocket skin shape should be evaluated for aerodynamic heating, drag, or stability problems that may result from these changes. A major element in overall mission analysis is the evaluation of launch vehicle stability (both static and dynamic). The payload configuration and structural bending characteristics must be adequate for acceptable flight parameters to be satisfied. Flight worthiness should be established during the initial design process; final mission analysis results are presented at the Mission Readiness Review.

4.3 Other Payload Design Considerations

Other factors which influence successful design practice include:

4.3.1 Accessibility

Access to internal components should be considered during the design phase of the mission lifecycle. Payload internals should be positioned and oriented in such a way that they can easily be accessed. For example, reset devices, remove before flight items (lens covers, inhibits) and battery connectors should all be close to a door or accessible without needing to disassemble the payload or subsection. Doors through payload skins should be sized appropriately for access. Components that may need to be replaced should be placed close to a door and the door should be large enough to remove the component and use tools to do so.

4.3.2 Availability of Parts

Consider the use of stock parts and components, also referred to as *Commercial Off the Shelf* (COTS) to minimize the cost of custom components and lead times. In recent years, supply chain constraints and limited inventories have increased lead times substantially. Confirm lead times with the supplier, do not assume a lead time from a catalog or website. Long lead time parts and components should be identified early in the design process and preemptively ordered to prevent mission delays. Avoid parts and components that cannot be easily replaced.

4.3.3 Dynamic Balance

Designing symmetric systems (relative to the central axis of the payload) will decrease the time needed to nullify payload imbalance during T&E balance operations. This consideration should extend to different configurations of the payload (such as from a launch configuration to a deployed configuration). In addition to saving time during T&E, the amount of mass needed to correct imbalances will decrease which may improve apogee and similar requirement metrics. Deployable booms should be paired symmetrically across the payload axis to decrease dynamic imbalance. Science teams should provide sympathetic booms (aka dummy booms) if a single, deployable, instrumented boom is to be flown.

4.3.4 Cost

The cost of each component should be considered based on form, fit and function. Consider manufacturing methods (such as parts machined from solid stock versus formed, welded, or cast). Excessively close tolerances on dimensions should be avoided. Let experience and engineering judgment be the guide. When purchasing electronic components; reliability may not go together with cost, "bargain basement" parts should be avoided.

4.3.5 Redundancy

Redundancy is desirable to decrease risk-based failure modes. While it is often easier to implement redundancy in electrical circuitry, it should also be considered in mechanisms. Examples include having multiple locking mechanisms on deployable booms, backup power systems for timed events, and logic-based software to monitor experiment state.

4.3.6 Weight

Depending on the capability of the vehicle and altitude requirements, weight may be a limiting factor. This is mission specific; generally, sounding rockets are not mass limited in the same way as other space hardware. Accurate mass estimates of scientific instruments and sections should be presented at the MIC. The NSROC Mechanical Engineer will generate payload mass properties throughout the mission lifecycle and will work with the NSROC Flight Performance Engineer to meet apogee and stability criterion. There are several techniques available to increase apogee and time above metrics, as required. Performance capabilities of launch vehicles are covered in Section 3 and Appendix A.

4.3.7 Testing

Experiment systems should be designed in a manner that it is efficient to test, debug and calibrate, especially when integrated in the payload system. It is encouraged to provide the necessary test connections utilizing standard interfaces, accessible through skin mounted connectors (umbilicals) or through an access door. Experiment monitoring during sequence tests and acceptance tests is necessary to ensure proper function and robustness.

Section 5: Payload Systems

Payload systems support the experiment and related instrumentation by providing telemetry, tracking, power, timing, thermal protection, mechanical structures, recovery aides, and various other functions. Effective payload system design is of primary importance to the success of each mission. Figure 5.1 shows an example of a complex payload system during integration. Designed for a Clemson University experiment, this payload features an attitude control system, several deployable sub-payloads, and a telemetry system for data transmission.

Figure 5.1: 36.361 UE Payload During Integration at WFF

5.1 Telemetry Systems

Telemetry is the primary means of obtaining data from sounding rockets. The instrumentation system provided to the customer depends upon the complexity of the experiment, the configuration of the instruments, and the size of the payload. In some cases, a separate instrumentation package is required; in other cases, the instrumentation and detectors are fully integrated in the same housing(s). In either case, instrumentation provides a means of formatting and transmitting scientific and housekeeping data, provides control signals to the experiment, provides timing, and supplies power if required. Telemetry systems vary in complexity, from a single link with no command or trajectory equipment, to systems containing as many as eight down-links, command, and trajectory hardware. Most systems operate with S-Band (2200 to 2400 MHz) down-links. Systems incorporating the command uplink function use 449.5 MHz for the uplink frequency.

5.1.1 Data Transmission Systems

Digital telemetry techniques are the predominant methods of transmitting data from a sounding rocket to the ground station in the NASA Sounding Rocket Program. Randomized Non-Return to Zero (RNRZ) or Bi-phase (BiΦ-L) Pulse Code Modulation/Frequency Modulation (PCM/FM) is the basic system employed. NSROC is now capable of supporting PCM/FM data rates up to 10 Mbit/s with the WFF93 Encoder and 14 Mbps with the Axon/KAM-500 encoder. NSROC is also capable of supporting SOQPSK, which will allow for data rates above 20 Mbps to a maximum data rate of 40 Mbps. Note: Since 2000, no FM/FM or hybrid (PCM + VCO) data system has been flown.

5.1.2 PCM/FM Systems

Five different types of PCM telemetry systems are currently used for NASA sounding rocket payload data requirements: the WFF 93 System, the Axon System, the KAM-500 System, the MV, and the Mesquito. Table 5.1.2-1 compares the characteristics of these systems. Additional descriptive and technical details are included in Appendix C.

Table 5.1.2-1: PCM System Characteristics

	Bit Rate	Word Length	Frame Size	Parity	Output Code	Frame/ Subframe
WFF93	78kbps-10 Mbps	8 - 16 bits	Up to 8k words	None	BIΦL, M, S NRZ-L, M, S RNRZ-L Conv NRZ-M Conv NRZ-L	Limited to 8k
Axon	Up to 40 Mbps	4-64 bits *Data Rate Restrictions	Up to 10E6 words	Odd/ Even/ None	Bi-ΦL, M, S NRZ-L, M, S DM-M, S RNRZL-15 RZ	Limited to 10k
KAM-500	Up to 20Mbps	4-64 bits *Data Rate Restrictions	Up to 250k words	Odd/ Even/ None	Bi-ΦL, M, S NRZ-L, M, S DM-M, S RNRZL-15 RZ	Limited to 32k
MV	Up to 20Mbps	8-16 bits	Up to 130k words	None	BIΦL, M, S NRZ-L, M, S RNRZ-L Conv NRZ-M Conv NRZ-L	Limited to 32k
Mesquito	Up to 2Mbps	16 bits	Up to 64k words	None	NRZ-L Randomized	Limited to 64k

5.1.3 WFF93 PCM Encoder System

The WFF93 PCM encoder is a general purpose, versatile, re-configurable, high rate, PCM telemetry system. The format structure is configured by a software. The hardware is configured as a modular, stack-up system with various data modules, which can be added or removed as required. A detailed description and module characteristics of the PCM Encoder System is included in Appendix C.

5.1.4 MV Encoder

The MV encoder is like the WFF93 encoder but with a faster bit rate, the capacity of 130K words per major frame, and two RS-232 input ports. The MV encoder has the same PCM output codes as the WFF93 and has a smaller footprint. What makes the MV encoder uniquely different from the WFF93 is that it only allows differential parallel inputs.

5.1.5 Mesquito Encoder

The Mesquito encoder was developed for small form factor telemetry systems. The Mesquito has all boards in a 2-inch x 2-inch stackable form factor. The encoder can be programed through a RS-232 interface and requires a nominal +12 VDC power source. The Mesquito can output a PCM stream at 1, 1.6, or 2Mbps which can be configured though the RS-232 interface.

The Mesquito has an analog input board which supports up to 16 channels per board. Each channel has 16-bit resolution with input from 0-5 volts. This system can support up to four analog input boards for a total of 64 input channels. The Mesquito can also support an RS-232 input board; this board can support two asynchronous data streams at popular baud rates including 1200, 19200, and 115200. The RS-232 board can accommodate three, time event inputs. Finally, the Mesquito has a serial input board which can support 2 channels of either synchronous or asynchronous data; this board is compatible with RS-422 and can support asynchronous baud rates of 19200 and higher. Each channel on the board includes a control signal for synchronous serial gated clock, enable, and inverted load.

5.1.6 Axon Encoder

The Curtiss-Wright Axon Encoder is designed to be future proof, flexible and a reliable platform. The encoder utilizes a solid modular chassis (16, 9, 6, 3 user-slots) and a suite of standardized modules for data acquisition. Each module and the system are configured by a software program designed for the PC environment. A more detailed description and module characteristics of the encoder is included in Appendix C.

5.1.7 KAM-500 Encoder

The Curtiss-Wright KAM-500 Encoder is predecessor to the Axon Encoder. The KAM-500's main difference is that it can combine multiple and different PCM Streams into one PCM Stream. A more detailed description and module characteristics of the encoder is included in Appendix C.

5.2 Attitude Instrument Systems Common to Several ACS's

Several types of sensors are used to provide payload attitude information. Some of these sensors meet the unique needs of a single type of attitude control while other sensors are versatile enough to be used across multiple platforms. The six instrument systems used in payload attitude control systems are as follows: GLN-MAC, Tern INS, STIM-300, Bartington magnetometer, Honeywell magnetometer, and the ST-5000 star tracker.

5.2.1 GLN-MAC Inertial Attitude Sensor

The GLN-MAC (**G**imbal-mounted **LN**-200 with Sandia **M**iniature **A**irborne **C**omputer) is a roll-stabilized inertial measurement unit for spinning vehicle applications. It was developed by Sandia National Laboratories in 1998. It was initially introduced to NSROC for use in 2005. Currently, this sensor is on end-of-life support and only used in the Celestial Attitude Control System (CACS).

The GLN-MAC is used to provide an attitude solution and body rates to the CACS; this sensor is also the flight computer for the CACS.

5.2.1.1 Description

The GLN-MAC consists of an LN-200 Inertial Measurement Unit (IMU) mounted on a gimbaled platform that is aligned with the spin axis of the rocket. The platform is driven by a motor and its position is measured by a resolver. This system provides power regulation for its various components, platform control, and computational capability for body rate measurement, attitude solutions, and control computations for the CACS.

The LN-200 contains gyros and accelerometers. Specifically, the LN-200 uses three orthogonal solid-state fiber optic gyros (FOG) and three solid-state MEMS accelerometers to sense the motion of the payload. This IMU can measure accelerations of up to 40 g and angular rates of up to 1,432° per second.

The primary output is an asynchronous data stream containing the measurements. It also has other outputs that are specifically used for the control function in the CACS. There are also some basic analog health monitoring outputs.

5.2.1.2 Function

The GLN-MAC has two modes – inertial and caged. The inertial mode is used when the payload is spinning. In this mode, the gimbal rotates causing the LN-200 to experience very little total roll rotation. A resolver reads the roll angle of the gimbal so the GLN-MAC can reconstruct the attitude and rate information of the payload. This improves the accuracy of the LN-200 by greatly reducing the measured roll angle and therefore the scale factor error.

When the GLN-MAC is caged, the gimbal is controlled to a constant angle and the LN-200 is not allowed to rotate relative to the rocket. This reduces the noise in measurements due to platform motion. The cage mode is electronically controlled yet not completely free of motion. This mode is only used after the payload has been de-spun.

GLN-MAC

GENERAL CHARACTERISTICS

Spin Isolation……..….. ±6 Hz

LN-200 Gyro Performance (1σ)

Bias Repeatability……………………..……… 1°/hr

Random Walk…………………..……...0.07°$\sqrt{\text{hr}}$

Scale Factor Stability……..…………… 100 ppm

Bandwidth……………………..…..………<200 Hz

Operating Range (pitch and yaw)… ± 1432°/sec

Quantization…………………..…... 1.9 μ radian

LN-200 Accelerometer Performance

Bias repeatability………….…………200 μg (1σ)

Scale Factor Stability……………..……300 ppm (1σ)

Noise………………………………500 μg/$\sqrt{\text{Hz}}$

Bandwidth………………………………100 Hz

Operating Range……………………..…… ± 40 g

Nominal Dimensions

Volume……………..…112 in³ (1841.8 cm³)

Height…………………… 8.39 in (213 mm)

Diameter ……………..…. 5.38 in (137 mm)

Mass………………… 6.63 lbm (3.01 kg)

Electrical Characteristics

Operating Voltage………… +28 V ± 4 V

Current (caged)…………………. 950 mA

Current (isolated)……….…... 0.95 – 4 A

Start-Up Time…………..… < 60 seconds

Data Output Rate (CACS) ………. 50 Hz

5.2.2 Tern INS (Inertial Navigation System)

The Tern INS is a roll-stabilized inertial navigation system for spinning vehicle applications. It is the successor to the GLN-MAC. It uses the electro-mechanical elements and the LN-200 of the GLN-MAC. The electronics and software have been completely modernized and advanced by NSROC. The first test flight of this sensor was on May 16, 2017, on Hesh/36.317 and has since become operational in 2020. The sensor has been integrated into the NIACS and is used in the telemetry Gyro application. It is also being designed into an update of the solar pointing ACS. The name, Tern, is a hat-tip to the Artic Tern than circumnavigates Earth.

The Tern INS intentionally took a different design approach than the GLN-MAC. It provides no additional usable computation resources. It provides body rates, attitude solutions, and navigation solutions for measurement and control purposes. It provides all data at 400 Hz for control; measurements are available at either 100 Hz or 400 Hz. The unit provides a configuration capability to adjust the unit to the specific application and requires no application-specific programming. The mechanical interface to the Tern INS is the same as the GLN-MAC; however, the electrical interface is dissimilar.

5.2.1.1 Description

The basic elements of the system are like the GLN-MAC. It consists of an LN-200 Inertial Measurement Unit (IMU) mounted on a gimbaled platform that is aligned with the spin axis of the rocket. The platform is driven by a motor and its position is measured by a resolver. This system provides power regulation for its various components and a computational board. The computational board provides platform control, determination of body rate measurement, attitude solution, navigation solution, and distribution of the data products.

The primary output includes a 100 Hz asynchronous data stream to provide the measurements to the ground and a 400 Hz asynchronous data stream for control applications. It also has auxiliary isolated data streams that can be used by other customers on the payload. There are also some basic analog health monitoring outputs available.

5.2.1.2 Function

The system was carefully designed to synchronize the LN-200 and resolver measurements. This provides excellent payload measurements. There is a 1-pulse-per-second signal that is provided to the telemetry system synchronized to the LN-200 with approximately 2 μ-sec delay.

The Tern, like the GLN-MAC, has an inertial mode which roll-isolates the LN-200. The other mode that the Tern offers is filtered-braked. This mode is specifically for very low noise measurements for non-spinning applications. The unit has novel resolver conversion technology that provides a roll-rate measurement that is 15 – 20 times quieter than the GLN-MAC.

The system provides a semi-autonomous initialization facility. The user provides the azimuth and time before launch of the initialization. The unit determines its elevation and roll offset. It combines this information with the location (from either GPS or user input) to set the initial attitude and to initialize the navigation solution. The system can also be initialized in the J2000 frame of reference.

Tern INS

GENERAL CHARACTERISTICS

Spin Isolation……..….. ±6 Hz

Nominal Dimensions

Volume……………..…105 in^3 (1723 cm^3)

Height………………….7.85 in (196 mm)

Footprint ………..5.38 in (137 mm)

Main Body Dia. ……….4.13 in (105 mm)

Mass………………… 6.25 lbm (2.84 kg)

Electrical Characteristics

Operating Voltage………+24 V – +36 V

Current (stationary)………….. < 500 mA

Current (isolated)……….….. 0.45 – 2+ A

Start-Up Time…………. 10 – 20 seconds

Output Data

Basis reporting…….100 Hz, 115.2 kbaud, 8-N-1

Control use……400 Hz, 1.5 Mbaud, 8-O-1

Auxiliary…… 2 basic plus 2 basic or control use

Resolver

LN-200 synchronization…………0.75 µs ± 9.3 µs

Noise…………………..……..……1 arcsec, 1-σ

LN-200…………………see specs in GLN-MAC

Roll Rate Jitter

Non-spinning ……………...……..±0.03°/s, 1-σ

Spinning, 4Hz ………….. ±1.0°/s – ±4.0°/s, 1-σ

Angular Accuracy

Relative, 30 min ………….. ≤ 0.5°, 1-σ, per axis

Absolute, real-time, 10 min flight..1.0°, 1-σ, per axis

Navigational Accuracy*

Position, 10 min …………..…… ≤ 2,780m, 1-σ, per axis

Velocity, 10 min …………. ≤ 12.8m, 1-σ, per axis

* Flight history indicates substantially better performance

GPS blending configurable

5.2.3 Sensonor STIM-300

The STIM-300 is a small, lower cost inertial measurement unit (IMU) that is used in the Digital NSROC Magnetic Attitude Control System. This instrument is being considered for a lower cost, lighter weight, roll isolated IMU than the Tern INS. The unit provides measurements on 3-axis body rates, 3-axis accelerations, and 3-axis inclinations at a rate of 125 to 2000 Hz, depending on the configuration.

STIM-300-1600-80

GENERAL CHARACTERISTICS

Nominal Dimensions

Volume…………….1.99 in³ (32.6 cm³)

Height…………… 0.846 in (21.5 mm)

Length…………….1.764 in (44.8 mm)

Width …………….1.520 in (38.6 mm)

Mass……………… 0.121 lbm (55 gm)

Electrical Characteristics

Operating Voltage……... +5 V ± 0.5V

Current …………………... < 400 mA

Connector………. Micro-D, 15, female

Output Data (Configurable)

Measurements..….rate, acceleration, inclination

Protocol…374.4k – 1.8432 Mbaud, 8-N-1

Sample Rate… 125 – 2000 Hz, cfg dependent

Rate Gyro

Full Scale…………………………±1600°/sec

Scale Factor…………………….… ±500 ppm

Bias……………………………….±250°/hr

Angle Random Walk………..……..…0.3°/√hr

Orthogonality……..………………..±0.2 mrad

Bandwidth………………………16 – 262 Hz

Accelerometer

Full Scale……………………………..±80 G

Scale Factor……………………… ±100 ppm

Orthogonality……..…………….….. ±1 mrad

Bandwidth………………………16 – 262 Hz

5.2.4 The Bartington MAG-03MS Magnetometer

The solar pointing ACS (SPARCS) uses the Bartington MAG-03MS magnetometer to determine the payload orientation with respect to the local magnetic field. Specifically, SPARCS VII uses it to determine and control its roll orientation as it is pointing to the Sun.

The Bartington MAG-03MS is an analog 3-axis magnetometer which is composed of 3 fluxgate sensing elements mounted orthogonally on a square base, which can then be mounted on the payload. Each element produces an output voltage signal proportional to the component of the magnetic field along its sensing axis. Together, the trio can measure both the magnitude and direction of the magnetic field. Some key characteristics of the magnetometer are described below:

- Power supply: ±12 V
- Dynamic range: ±70 uT
- Output voltage: ±10 V
- Frequency response: flat from DC to 1 kHz with a bandwidth of 3 kHz

This magnetometer is usually mounted in the ORSA section near the nose of the payload to minimize the magnetic interference from the other electronic systems. Even so, its analog signals are susceptible to corruption as they travel through a long cable to the ACS section. A procedure has been established to calibrate this magnetometer against systematic magnetic interference in its operational environment and to characterize the unit-to-payload mounting misalignment.

5.2.5 Honeywell Magnetometer

The HMR2300 is a digital magnetometer which uses an orthogonal triad of magneto-resistive sensors to measure the local magnetic field. Each sensor has a range of ±2 gauss with a resolution of less than 70 μgauss and can provide data at rates of up to 154 samples per second. To minimize magnetic interference from other payload systems, the magnetometer is usually placed near the forward or the aft end of the payload rather than within the attitude control system (ACS) section. The HMR2300 data is then transmitted through a serial interface from its remote location to the ACS. Whatever magnetic interference remains can be calibrated out after the magnetometer has been integrated with the rest of the payload.

Currently, this magnetometer is used in two ACSs: the Digital NSROC Magnetic ACS (DNMACS), and the NSROC Inertial ACS (NIACS) as an optional sensor. During phases of a mission when alignment relative to the magnetic field is required, the information from the magnetometer is used to align the spin axis of the payload with the magnetic field or in a specified direction relative to it. The NIACS also offers a modeled magnetic control. For this approach, the magnetometer may still be included in the ACS for monitoring purposes.

5.2.5 ST-5000 Star Tracker

The **S**tar **T**racker **5000** (ST-5000) is a low-cost star tracker which can determine pointing from any location in the sky. It was developed by the Space Astronomy Laboratory at University of Wisconsin – Madison with funding from NASA.

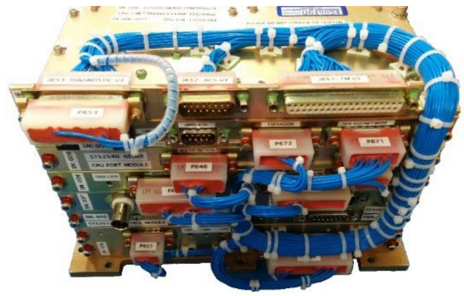
The ST-5000 is currently used in NSROC's Celestial ACS to align sounding rockets to stellar targets. This star tracker has the capability to provide both attitude information and digital images of the star field.

5.2.5.1 Function

The ST-5000 contains a sensor which continuously captures images of the 5.4° by 7.4° portion of the sky it is pointed towards. The software tracks up to 32 stars at one time, comparing them with the stars in the ST-5000's on-board library to determine the payload's orientation. The ST-5000 does not require any prior knowledge of its orientation to determine its attitude, its Lost in Space (LIS) feature can produce an initial attitude solution within 1 to 5 seconds. Once the attitude has been determined, the system provides quaternion updates to the attitude at a rate of 10 Hz.

In addition to the quaternion, the ST-5000 can also transmit the images taken by the star tracker. Progressive Image Transmission is used for sending these images, which allows full field-of-view images to be transmitted in less than 30 seconds over a 19.2 kbaud RS-422 telemetry downlink.

ST5000 Star Tracker



Performance Capabilities

Field of View…………………...……... 5.4°×7.4°
Star Catalog…….………......+4 to +8 magnitude
Lost In Space - LIS………...... Quaternion attitude
Progressive Image
Transmission (PIT)...................................... < 30 sec
Temperature…………………. ….. -20°C to 40°C

Star Tracking Capabilities

Pitch/Yaw Error……………………... 0.54 arcsec
Roll Error…………………………….... 17 arcsec
Pitch/Yaw Jitter……………………….. 0.5 arcsec
Roll Jitter………………………………. 10 arcsec
* Measurement from August 2007 Flight

Data Output

Update Rate…... 10 Hz
RS232/RS422…………………. 19.2-115.2 Kbaud
Analog (several outputs, ex. temp, error, status)
……………………………………………... 0-5V

Nominal Dimensions

Sensor Head
Length…………………………... 8.1" (20.5 cm)
Diameter……………......……... 5.0" (12.8 cm)
Mass……………………......... 4.0 lbm (1.8 kg)
Electronics
Length…………………………... 9.1" (23.0 cm)
Width…………………………… 5.7" (14.5 cm)
Height…………………………... 5.7" (14.5 cm)
Mass……………...…….. … 6.8 lb_m (3.1 kg)

Electrical Characteristics

Operating Voltage……………………. +28 V ± 6 V
Current …………………..………………... 600 mA

5.3 Onboard Sensors and Instruments

5.3.1 TTC Flight Recorder

The TTC is a ruggedized flight recorder designed to sustain a crash. The TTC can be programed and communicated with via a GUI and an Ethernet interface. The TTC can support up to 1Gbps and be equipped with a solid-state hard drive with a capacity up to 2TB. The component is modular allowing for simple drop in additions of more Ethernet ports and other components. The TTC also is fitted with 9-pin DEMA connector cards that allow for serial inputs.

NSROC uses the TTC to record data at faster speeds than traditional telemetry can support and allow customer interface to raw sensor data over Ethernet. NSROC also uses the TTC as a data backup if the telemetry stream was lost during flight the sensor data can still be recovered since the flight recorder is designed to withstand a crash. The drawbacks of the TTC are that it's larger to incorporate into a payload system and is an expensive component.

5.3.2 Accelerometers

NSROC currently offers the possibility of three accelerometers. The current standard telemetry accelerometer is the Setra 141 which has a linear sensing range up to +/- 60G at +/-3dB and a frequency response from 0-1KHZ where the sensor produces a high-level instantaneous DC output Proportional to sensed acceleration. The Setra is a single axis accelerometer so three are used in each payload for x, y, and z axis acceleration data.

If the Mosquito or the WAASP are used the ADXL 250 accelerometer is included. The ADXL 250 can be set to either have the range of +/-25 G or +/-50 G. The ADXL is a dual axis accelerometer built on a single monolithic integrated circuit. The ADXL 250 is also used where obsolete accelerometers were required for rehabilitated payloads. The third Accelerometer is just an updated version of the ADXL which is the ADXL 278. This chip simply replaces the ADXL 250 but only has a range of +/-50.

5.3.3 Vibration sensors

NSROC currently uses the Dytran 3055D4 sensors combined with the TIVAS signal conditioning unit to obtain vibration data. The key features of the Dytran 3055D4 are the housing is made of titanium, it is hermetically sealed, its base is isolated, weighs 10 grams, has high resonant frequencies (>25 kHz), a tight sensitivity specification of +/- 5%, and a frequency response of 1 Hz to 10 kHz. The sensor has a 50 mV/g sensitivity with a 100 g range.

The signal conditioning box Triaxial IEPE Vibration Accelerometer System (TIVAS) provides power to the sensors and filters out unwanted noise. The TIVAS unit can support three sensors. The TIVAS unit also provides a 0-5v output for each sensor for the PCM encoder analog input. TIVAS comes in two variations based on the cut off frequency required. For monitoring random vibrations, the TIVAS 3.5k Hz unit is used. For monitoring shock, the TIVAS 35k Hz unit is used.

5.3.4 Magnetometer

NSROC uses the Bartington MAG-03MS series, which is used as a standalone attitude determination sensor or in the NMACS magnetic attitude control system. The magnetometers used are flux gate devices with a ±600 milligauss or 60,000 Gamma sensing range, providing an accuracy of approximately 3 or 4 percent when calibrated inside the payload. For flights near the equator, a 450 milligauss magnetometer is used.

NSROC also uses the Billingsley TFM100-G2, which is a standalone attitude determination sensor. The device is an ultra-miniature triaxial fluxgate magnetometer with a sensing range of ±60 μT.

Magnetometers sense payload attitude relative to the earth's magnetic field and unless aligned perfectly with the field results in attitude knowledge of relative angular displacement from the local magnetic field line. This data, along with data from supplemental sensors, is used to construct absolute payload attitude. For applications where accuracy is a prime consideration, extreme care must be exercised in the placement of the unit to avoid stray magnetic fields generated within the payload, and high static fields exhibited by magnetized ferrous material.

5.3.5 Ethernet VIA Telemetry System (EVTM)

The EVTM provides high speed ethernet telemetry data rates up to 40 Mbps using standard UDP ethernet protocols and standard ethernet interfaces.

5.3.6 Space Eye 320 Ethernet Camera

The Space Eye 320 (SE320) is an IP camera which outputs H.264 compressed video. This global shutter camera can operate at 1920x1080p resolution at 60 fps with a target bit rate of 16 Mbps. The camera can support up to two simultaneous output streams, one of which will be the high-quality stream and the other a low-quality stream. The intention for the two data streams is that one stream could be telemetered while the other stream is sent to a network recorder. Timestamps with absolute time can be overlaid onto the video.

5.3.7 NSROC Vacuum Monitoring Sensor (NVMS)

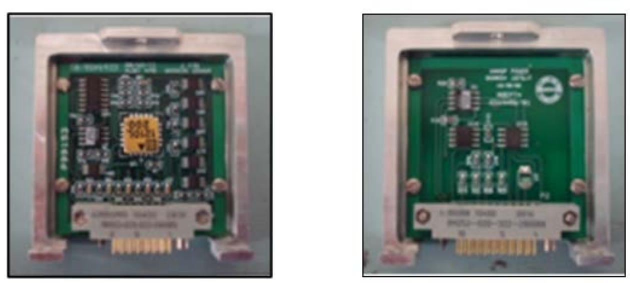
The NSROC Vacuum Monitoring Sensor (NVMS) is a small, low power, standalone unit to simply ascertain the vacuum system performance. The NVMS uses a single 0-5v temperature compensated output with a sensing range of atmosphere to 1E-5 torr.

5.3.8 Solar/Lunar Sensors

The current solar aspect sensor was developed by Army Research Laboratories and the technology was transferred to the NASA Sounding Rockets Program. The solar aspect measurement is obtained by incorporating 4 to 10 solar sensors located on the payload skin at predetermined angular locations. The number of sensors and locations depends on the precision required. The Solar Likeness Indicating Transducers (SLITs) are restricted slit silicon solar cells mounted in a housing that includes obstructing geometry that restricts the amount of sunlight that enters and impinges upon the photoelectric cell. The restriction of light properly maintains a constant surface area of solar sensor illumination over a nearly theoretical half-plane of light acceptance. Thus, the device produces a significant output when aligned with solar field and no output when misaligned. In a rotating body, the photocells transmit a pulse train that can be used to determine an attitude vector to the sun. For additional precision in post flight attitude determination, the SLIT sensors are used in conjunction with a magnetometer to provide a single-axis or three-axis attitude solution. The solution can be accurate to three degrees depending on relative sun vector and magnetic field vector orientation.

5.3.9 Wallops Accelerometer & Attitude Sensor Package (WAASP)

The Wallops Accelerometer & Attitude Sensor Package is an attitude determination sensor system designed to be used on sounding rocket payloads. The WAASP has the capability to link up to additional sensors through two I/O ports and it has the ability for on-board data processing and self-contained telemetry. Currently the WAASP has three-axis accelerometers, three-axis magnetometers with additional redundant channels, a roll rate sensor, and the capability to support a Sun sensor. NSROC is currently in progress of designing and building a new solar sensor to bring the WAASP up to full capabilities.



Sensor Board Power Board

Figure 5.2: Wallops Acceleration and Attitude Sensor Package (WAASP)

5.3.10 Video Cameras

NSROC can offer specialized television cameras featuring low power consumption, compact size, and very high sensitivity for sensing star backgrounds, in-flight events such as payload ejections, and rocket motor performance. Intensified charge coupled device cameras have a threshold sensitivity of 10^{-6} ft-candles face-plate illumination and are compatible with standard broadcast monitors and recorders. Cameras used on Sounding Rocket payloads operate from a 12-volt D.C. supply and require less than 10 watts of power. Volume is typically 75 cubic inches or less for most TV cameras used and weight is less than 30 ounces. The output from these cameras is transmitted using a wide band TV transmitter, or more recently via a TV video compression deck in the WFF93 PCM encoder. These cameras, when combined with the command uplink system hardware, can be used to fine tune in-flight payload targeting.

NSROC is also capable of supporting both high definition and standard definition onboard cameras. The program uses ruggedized, bullet cameras with a variety of lens options in compact size for harsh and small environments. The bullet cameras are roughly the size of a roll of quarters. The main implementation of these cameras is in the Aft Looking Video System or ALVS. ALVS allows up to four cameras through a system of mirrors to look towards the aft of the rocket. The four video streams are then multiplexed into a single video stream that is configurable to suit the needs of the customer. The ALVS is capable of not only recording onboard through a DVR but capable of outputting live video.

The HD camera system includes a harsh environment, MPEG-4 HD Video Encoder that allows digital video data to be inserted into the PCM stream. Once received on the ground the digital video data is then separated from the PCM stream and decoded in the ground station. This allows the video stream to not only be recorded but allows live viewing as well. The encoder system is 1.7 lbs., 49 cubic inches, consumes 11 watts of power and is capable of outputting up to 1080 p resolution. NSROC utilizes a compact, digital HD camera, consuming less than 3 W of power. The camera has a C-mount lens and comes with configurable image settings.

5.3.11 Rate Sensor

A combination rate sensor and accelerometer package, Inertial Science Inc. model ISIS-IMU (IMU = Inertial Measurement Unit) has been flown on several recent sounding rocket missions. The package is specified as a fully compensated IMU with 6 Degree of Freedom and provides either discrete channel analog outputs or combined sensor data on a single asynchronous stream output. Rate sensing of up to 5000 degrees per second and acceleration sensing up to 500 G's is possible with this unit.

Another rate sensor that has recently been packaged and flown on a sounding rocket utilizes an Analog Devices ADXRS150 angular rate gyro sensor or gyroscope. This device is a single axis sensor that uses surface micromachining process for the rate sensing and integrates all the signal conditioning electronics into one 32 lead Ball Grid Array package. The sensor is configured to measure rates of +/-150 degrees per second for a 0 to 5 Volt output.

5.3.12 Strain gauges

NSROC is capable of supplying strain gauges and associated signal conditioning if the customer requires them. Currently NSROC uses strain gauges from Vishay Micro-Measurements. The strain gauges come with preset temperature profiles and calibration equations. The gauges can withstand a wide temperature range and can sense a range of +/- 5284 με with a resolution of +/- 5.2 με. NSROC can install multiple singular strain gauges or sets of two through four.

5.4 Transmitters

A variety of telemetry data transmitters are available with a range of RF output power from 2 to 20 Watts. Most of the transmitters are true FM units and are AC coupled. The Program has a new high data rate, bandwidth efficient SOQPSK transmitter. Transmitters used on a given project are sized to provide the necessary link margin while at the same time minimizing power requirements. Available transmitters have frequency responses ranging from 1.5 MHz to over 40 MHz and cover the lower and upper S-Band frequencies (2200-2400 MHz). Newer models are frequency agile and can be set to cover lower and/or upper S-Band frequencies. The newest model transmitters accept TTL or RS-422 data and clock modulation inputs and automatically adjust carrier deviation for optimum setting. Older analog modulation input models can accommodate pre-modulation filtered PCM data streams up to 20 MB as well as TV camera NTSC video signals.

5.5 Command Uplink Systems

Several different command systems are available; selection depends upon the complexity of the command requirements, the launch location, and the other flight hardware configurations on the payload. All command systems require an up-link at 449.5 MHz. Ground stations are equipped with capabilities ranging from one to fifteen discreet ON/OFF commands, to pointing a sensor/instrument at various areas of the sun or other targets. The command systems utilize FSK Modulation. System command rates vary from several seconds per command to several commands per second.

5.6 Telemetry Antennas

Several types of antennas can be used; selection is determined by the function to be performed, the payload and vehicle configuration, and the radiation pattern coverage required. For data transmission, a family of S-Band micro-strip antennas has been developed. These antennas, in 4, 14, 17.26, and, 22-inch diameters, are configured to be flush mounted with the telemetry skin as well as some that are designed to be installed beneath nose cones or on other RF transparent skins and provide varying degrees of thermal protection for different vehicle types. These wrap-around units require from 4 to 6-3/4 inches axially along the payload body. Micro-strip and strip-line antennas are made by New Mexico State University, Haigh-Far, AntDevco, and Wallops Flight Facility respectively. All these downlink data transmission antennas are linearly polarized and provide a pattern that is basically omni-directional, with nulls at the nose and tail of the vehicle.

For command purposes, the most used antenna type is the quadraloop and consists of four individual elements. Radiation coverage can be adjusted by the way the elements are connected (phased), and this is frequently done to provide maximally aft or maximally broadside patterns. Antenna element phasing results in a circular pattern polarization. Combined with selectable right or left hand circular polarized helix ground transmitting antennas circular polarized receiving antennas results in optimum transmitted to received antenna signals.

For radar transponder applications NSROC uses circular cavity backed right hand circular polarization helix antennas. These elements are mounted 180° apart and are fed from a two-way power divider.

Special antennas such as cavity backed slots, bent wires, disc micro-strips, and rectangular micro-strips have been designed for unique applications in both the data acquisition and command areas.

5.7 Instrumentation and Experiment Power Systems

The electrical power for instrumentation and experiment electronics on sounding rockets is derived from batteries. The selection of the battery system is based on a consideration of weight, size, capacity, and system power requirements. Although several types of battery systems are available, the ones predominantly used by WFF are nickel cadmium (NiCad) and have a very successful flight history.

5.7.1 Nickel Cadmium

All the nickel cadmium cells that are used in sounding rocket payloads are of the cylindrical sealed cell design. These cells incorporate a resealable safety pressure release vent and are virtually maintenance free. Advantages of the nickel cadmium battery system are:

- Much less expensive
- Can be mounted in any position
- Longer life span and cycle life
- Same battery that is used for environmental testing is used for flight
- Not sensitive to overcharge
- Maintenance free
-

Available NiCad batteries currently in use include the following: 600, 1,400, 2,300, 5,000 and 8,000 milliamp-hour capacity.

Table 5.7-1 Comparison and Performance of NiCad Battery Systems

Comparison and Performance of NiCad Battery Systems					
Temp = 25° C System Voltage, Nominal = 28 V					
Cell Type	**2/3 AF**	**A**	**C**	**D**	**F**
Manufacturer	**American Toppower**	**American Toppower**	**Saft**	**Saft**	**Saft**
Electrical Characteristics					
Rated Capacity (Ah)	0.6	1.4	2.3	5.0	8.0
Open Circuit Voltage (Fully Charged)					
Cell (V)	1.4	1.4	1.4	1.4	1.4
24 Cell Pack (V)	32.4	32.4	32.4	32.4	32.4
Average Plateau Voltage at C/1					
Cell (V)	1.2	1.2	1.2	1.2	1.2
24 Cell Pack (V)	28.8	28.8	28.8	28.8	28.8
Physical Characteristics (Cell)					
Weight (oz)	0.63	1.2	2.64	5.27	7.76
Diameter (in)	0.66	0.066	0.97	1.26	1.26
Height (in)	1.14	1.92	1.93	2.29	3.49
Physical Characteristics (Pack)					
Weight (lbs)	1.59	2.46	5.94	11.54	16.73
Length (in)	4.45	4.45	7.18	8.79	8.79
Height (in)	1.74	2.6	2.53	3.12	4.28
Width (in)	2.99	2.99	4.82	5.89	5.89

5.7.2 Voltage Output

The nominal system voltage output from the battery pack is 28V DC ±4V. PI's requiring voltages other than the nominal 28V DC are requested to provide their own power conditioning. The experiment's 28V can be supplied from the instrumentation batteries or from a separate 28V battery pack located in the instrumentation section. Some PIs prefer to supply their own battery.

> **Note:** The PI should provide circuit protection to assure that other flight circuits are not affected by short circuits occurring in the experiment payload equipment.

5.7.3 Power Control Distribution (PCD)

NSROC provides two types of power control and distribution units: the telemetry 28V PCD and the Experiment Variable V and split +/-V PCD. The PCDs are primarily for switching the electrical systems from external power to internal battery power. Both PCD units have bus voltage and state monitoring circuitry and can be controlled via the block house ground support equipment through RS422 lines. Through one RS422 line, up to six PCD units in any combination can be controlled.

5.7.4 Switching

All on-board power switching relays are backed up by first-motion lift-off switches to prevent power loss due to inadvertent relay transfer.

5.7.5 Pyrotechnic Power Supply

Power for payload pyrotechnic functions is normally supplied from a separate pyro battery. Voltage is made available to the pyro bus through 50,000-foot altitude switches. Squib monitor circuits provide telemetry with an indication of squib firings.

5.7.6 High Reliability Intermediate Power Supply (HiRIS)

The High Reliability Intermediate Power Supply (HiRIS) is a 28v input, ±12v isolated output, DC to DC converter. This converter's outputs can supply a total of 30W. The HiRIS comes with an inhibit switch, indefinite short and overload protection, light EMI filtering and a case mounted thermistor.

5.8 Flight Event Timing Systems

5.8.1 Drop-in Replacement Timer (DiR Timer) (DiRT)

The DiR Timer (DiRT) was developed to allow in-payload event time reprogramming. The DiRT has an Electronically Erasable (EE) Programmable Read Only Memory (PROM). These monitor functions, as well as external programming for event times, is accommodated by a nine-pin connector. The DiRT can be programmed with a computer through a USB to RS-232 converter cable and is used in both the instrumentation systems and in hazardous CDI systems. The timer has thirty outputs that can be enabled and disabled at specific times. These DiRT is initiated by either a lift-off switch closure or an umbilical release at lift-off

5.8.2 Barometric Switches

Barometric switches are used to hold off initiation of functions due to contact chatter during motor burn. Barometric switches operate at preset altitudes to activate or turn off various electronic functions such as internal power. Usually redundant switches are installed; however, they are sensitive to location. Good design requires that the switches be placed in a location on the payload where they will not be adversely affected by aerodynamic air pressures. Available altitude switches include the following: 5,000 ft, 15,000 ft, 16,500 ft (down leg), 30,000 ft, and 50,000 ft.

5.9 SWARM

The Swarm system is used to allow for remote science data collection to improve spatial resolution of data. The system is comprised of 4 ejectable sub-payloads (Dallas) and a main payload Swarm section. The Dallas sub-payloads are ejected from the main payload and then collect data and transmit it back to main payload, where it is received and combined into a single telemetry downlink to ground. The sub-payloads are ejected either by a compressed spring release or by rocket motor.

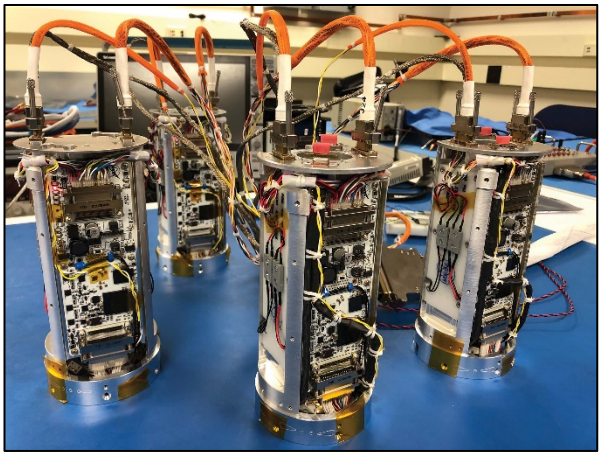


Figure 5.3: SWARM System

5.9.1 Dallas Sub-payload

The Dallas sub-payload consists of an experiment section and support section. The experiment section is designed by the science team to fit within the allowable dimensions. The support section is NSROC-controlled and has the components, described in section 5.9.1.1 through 5.9.1.11.

5.9.1.1 Control Card

The control card fulfills the roles of PCM encoder, housekeeping monitor, timer, and sensor suite. It can output PCM data at up to 1 Mbps with a programmable matrix. It outputs an async housekeeping channel that includes Dallas voltage & current, experiment voltage & current, transmitter voltage & current, and monitors for umbilical and eject break wires. It outputs a sensor async channel from an integrated IMU that includes 3-axis gyro, 3-axis magnetometer, and 3-axis accelerometer data. It also has an integrated 2-axis analog magnetometer and 3-axis analog accelerometer. There are 8 user-defined analog inputs in addition to 8 pre-defined analog channels for the analog sensors, voltage, current, and 1pps from the MCU chip. There are 4 user-defined async channel inputs in addition to the pre-defined channels for the sensor and housekeeping data. There is a user defined GPIO that can be programmed to “time since eject”.

5.9.1.2 Transmitter

The transmitter is an Upper S-band 2W Quasonix nanoTX. The frequency is programmable, each Dallas operates at a different frequency. The power level is also programmable and can be switched. Under normal operation, the transmitter will operate at low power while the sub-payload is stowed and will switch to high power at a set time after ejection, with timing controlled by the control card.

5.9.1.3 Antenna

The antenna is an Upper S-band dipole antenna that is mounted on the aft end of the sub-payload.

5.9.1.4 Batteries

The sub-payload uses sets of NiMH batteries that provide +9.6V. The battery configuration for spring-eject sub-payloads is rated for 1500 mAh. The battery configuration for rocket-eject sub-payloads is rated for 1000 mAh.

5.9.1.5 GPS (Spring-eject)

The GPS system is comprised of a JAVAD TRH-G2P receiver, a GPS auxilliary card that buffers the receiver output to an async channel and provides analog GPS housekeeping data (voltage, current, and 1pps), and an active GPS patch antenna, normally located on the forward end of the sub-payload. GPS is only available on spring-ejected SWARM modules.

5.9.1.6 Spring-Ejected Sub-Payloads

Spring-eject sub-payloads have an expected velocity of around 10 m/s and an expected spin rate of 1 Hz. They can be configured for GPS.

5.9.1.7 Rocket-Ejected Sub-Payloads

Rocket-eject sub-payloads have an expected velocity of around 100 m/s and an expected spin rate of 5 Hz. They include an integrated SAFE/ARM plug on the aft end and house the rocket ignition pyro. They cannot have GPS and have less battery capacity due to size of the rocket motor. Rocket-eject sub-payloads are normally programmed for lower bitrates to increase their effective transmission distance.

5.9.1.8 Main Payload Swarm Section

The Swarm receive section houses the Dallas sub-payload ejection system, receive system, downlink system, and power system.

5.9.1.9 Ejection System

The ejection system consists of the doors, the ejection tubes, and the associated pyros. The doors are normally made of fiberglass to be RF-transparent. The ejection tubes come in spring-eject and rocket-eject variants. All pyrotechnic events are controlled from external sources. The doors and spring-eject pyros are normally controlled by a main telemetry timer and pyro bus. Rocket-eject pyros are controlled by a payload CDI system, normally located in the telemetry section.

5.9.1.10 Receive System

The standard receive system consists of a wrap-around antenna, a band-pass filter, a LNA, and two Marko receivers. A single Marko receiver can receive 2 Dallas sub-payloads. The Marko receiver oversamples the Dallas link and has a defined fill pattern to replace stale data.

5.9.1.11 Downlink System

The downlink system consists of a WFF-93 encoder and a transmitter selected based on mission needs. The WFF-93 takes in data from the Marko receivers via a synchronous serial interface and the async housekeeping and sensor channels from the sub-payloads while they are stowed. The system will operate at 6 Mbps if the sub-payloads are at 1 Mbps and normally transmits in the lower S-band. The downlink antenna is normally located on the telemetry section.

5.9.1.12 Power System

A standard NSROC voltage regulator box provides +5V to the LNA and an APSU powers the Marko receivers. Power for the APSU, voltage regulator box, WFF-93 encoder, and transmitter are normally provided by a PCD system located in the telemetry section.

5.10 Trajectory Measurement Systems

Three types of tracking systems are or recently have been used on NASA sounding rockets: radar transponders, Doppler Ranging and GPS.

5.10.1 Radar Transponders

Radar transponders are used to enhance the tracking capabilities of radar. The transponder contains a receiver and a transmitter; both operate in the same frequency band as the tracking radar but are normally tuned to separate frequencies. This frequency separation is normally 75 MHz. The tracking radar interrogates the transponder by transmitting a pulse (or pulse pair depending upon the coding) at the proper frequency. Double pulse codes are normally set on an integer value between 3.0 and 12.0 microseconds. Upon receipt and detection of a valid interrogation (correct frequency and code) the transponder will transmit a reply pulse after a known fixed-time delay - typically 2.5 microseconds.

The power output from a transponder, ranges from 50 to 150 watts (pulse peak power) and provides a much stronger signal to the radar than is obtainable from the reflected skin return from the sounding rocket. The signal level received at the radar from a transponder, decays at 6 dB/octave with range, whereas the skin return decays at 12 dB/octave, thereby providing as much as two orders of magnitude greater range tracking capability when using a transponder. The transponder requires an external antenna system. On sounding rockets the current standard design incorporates two right hand circular (RHC) polarized helix mounted 180° apart on the skin, that are fed from a two-way power divider.

Transponders are used for several reasons:

- To provide full trajectory tracking when the radars do not have skin tracking capability through the full trajectory
- To provide discrimination between vehicles which are in flight at the same time by means of frequency and/or coding
- To provide a higher probability of obtaining tracking data right off the launch pad
- To provide higher precision data than is available from skin track due to higher signal to noise ratio and a point source target.

5.10.2 Doppler Ranging

Doppler Ranging has been consistently used in areas such as Andoya, Norway, where radar is not normally available. The Doppler Ranging technique uses a super stable, oven temperature controlled, crystal oscillator (ocxo) to obtain oscillator stability of about 1 x 10^-9 percent. The stable oscillator is used as the clock for the PCM encoder bit rate. Currently Norway can support Doppler Ranging at bit rates up to at least 10 M bits per second. Once the RF signal is received by the telemetry ground tracking antenna and demodulated by the telemetry receiver, the PCM stream is decommutated and the major frame frequency is observed. This observed frequency is then compared to a baseline frequency taken prior to launch. The difference in frequency can then be used to calculate the frequency shift. This Doppler frequency is a direct indication of payload position with respect to the telemetry tracking antenna; when the tracking antenna azimuth and elevation values are incorporated, a payload position solution can be generated. The key to this system is the stability of the payload PCM oscillator and the accuracy of the telemetry tracking antenna azimuth and elevation figures. Typically, telemetry tracking antennas resolve the antenna elevation and azimuth angles to .01 degrees whereas Radars resolve these to .001 degrees. The Doppler Ranging system provides a relatively cheap payload position solution method but with reduced payload position accuracy compared to Radar or GPS.

5.10.3 Global Positioning System (GPS)

The WFF GPS Flight System is based on a L1 band, civilian code GPS receiver, wrap-around antenna, and preamplifier. Wrap-around antennas are available in 22, 17.26, and 14-inch diameters. Time, position and velocity data, and timing signals are multiplexed and transmitted with the payload S-Band telemetry.

Ground support is provided by a portable briefcase pc or a laptop, which decommutates the S-Band downlinked PCM video and outputs display of payload position overlaying predicted path. Received payload GPS data can be reformatted to provide a slaving source for accurate pointing of tracking Radar's and telemetry tracking antennas.

5.11 Mechanical Systems & Mechanisms

5.11.1 Nosecones

Several types of nosecones are available for a variety of applications. These include 11° straight taper cones as well as a 3:1 ogive shape for 14 inch and 17.26-inch base diameters. These nosecones are typically available in aluminum or stainless steel, in either spun or formed shapes. Designs for a 22-inch diameter 19° conical nosecone are also utilized. Nosecones commonly have ballast added to them for payload stability. Nosecones are commonly assessed for heating from the trajectory and thermal protection can be added to them if necessary.

A deploying Clamshell nosecone is available in 19°, 17.26-inch diameter as well as 11°, 14-inch diameter for when a low altitude nosecone deployment is required.

Deployable nosecones utilize either spring cartridges or air springs to deploy longitudinally. When required, a Radial Ejection Ogive System (REOS) can laterally deploy a nosecone once it has ejected from the payload, so no wake is imparted on the payload instrumentation.

5.11.2 Structures and Skins

Skins for the 14, 17.26, & 22-inch diameter payloads are typically custom made. Standard systems have standard skins. Internal structures are also designed to fit each application, whether it be a telemetry section or for packaging several scientific instruments. Standard structure designs involve deck plates and C Channel longerons held internally with brackets and bumpers against the skin.

This table contains the internal diameter clearances of various skin joints:

	14 inches	**17.26 inches**	**22 inches**
Male Radax	12.37 inches	15.63 inches	20.37 inches
Female Radax	13.00 inches	16.26 inches	21.00 inches
Manacle Joint	12.37 inches	15.66 inches	20.37 inches

Skins that deploy and expose internal structures or components to space are called skirts and utilize manacle joints and compressed die springs to push off the main payload body. These skins deploy longitudinally and employ fiberglass cloth liners to prevent a hang-up during egress. There is also a design for a clamshell skirt that deploys radially away while spinning, for 17" payloads only.

5.11.3 Shutter Doors

Electrically powered vacuum shutter doors are available for 17.2-inch and 22-inch diameter payloads. These doors open to an aperture of approximately 15 inches and 20 inches respectively. The plate assembly opens 105°-107° degrees from stowed/closed position to allow ACS and science sensors a view through its aperture. In the past they have been used in forward and aft positions, but typically point toward the aft. NSROC maintains an inventory of them in various surface coatings (plain, gold iridite, and black anodized). The shutter door plates can be modified with viewing ports, baffles, or similar features. Shutter doors nominally close on the downleg trajectory at 100 km but the altitude may be lower if the payload is on a low trajectory.

5.11.4 Deployment Mechanisms

Deployment mechanisms actuated by pyrotechnic devices or other means are available for doors, booms, shutters, etc. Common pyrotechnic actuators are guillotine cutters for shearing bolts or retaining cords, pin pullers for releasing mechanisms, and gas generators for pushing pistons. Rotary motors have been used in the past, especially for the shutter door as well as side opening and closing doors. Mechanical Coil Springs are also typically used to deploy payload stages or sub-payloads, but air springs have also been used in the past. Air springs provide lower acceleration but longer impulse and faster velocities than standard springs. Constant force springs, low force plungers, and spring-loaded hinged flaps are also used in some applications.

5.11.5 Ejectables (EDS, SWARM, and Others)

The program has a history of designing payloads that separate. The distinction in nomenclature is dependent on the capability of the body that separates. For example, separating bodies that have their own telemetry and ACS systems are referred to as main-payloads and sub-payloads. Each body could be its own distinct payload if launched on its own launch vehicle. If, however, one of the separating bodies does not have both a telemetry and an ACS system, the pair is referred to as a mother-payload and daughter-payload. The program also has a history of flying "small" sub-payloads (4-50 lbs.) which are typically unique and custom designs specific to the mission. There are currently two, standard small ejectable deployment systems, chemical ejectables via the Ejectable Deployment System (EDS) and electronic/instrumented ejectables via the SWARM system.

5.11.5.1 Chemical Ejectable Deployment System (EDS)

EDS was developed to create a constellation of chemical disbursed clouds of Tri-methyl Aluminum (TMA) or a mixture of Barium, Strontium, Cupric Oxide, and Thermite for ground and aerial observations. The program is based off a single skin that deploys four ejectables via spring loaded doors and a rocket propelled ejectable. The system flies with anywhere between 1 to 6 skin systems, enabling up to 24 ejectables / chemical disbursements.

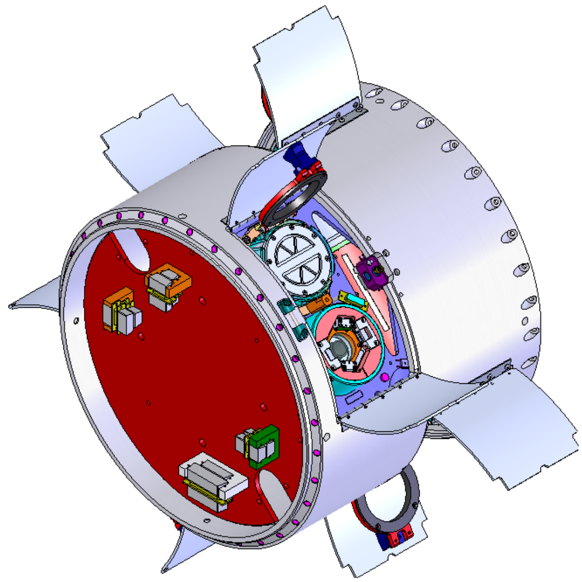


Figure 5.4: Single EDS Section with Installed Ejectables

EDS was developed in earnest from 2013 through 2017 and has had numerous science and test flights. It is a standard system as provided by NSROC ME, GNC, and LVE.

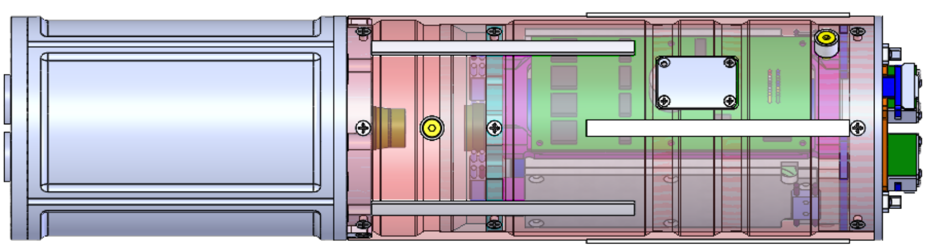


Figure 5.5: Chemical Ejectable (TMA Ampule)

The ejectable weighs between 5.3 and 6.2-lbs is 3.4 inches in diameter and 13.2 inches long. The front of the ejectable is the chemical ampule container, with a burst disc and pyrotechnic initiator(s). Aft of the ampule is the ejectable electronics, which is a redundant system of two Ampule Control module (ACM) boards with batteries that fire both the rocket motor and its initiator and the chemical ampule initiator(s).

Each EDS skins is 14.25 inches long. The mission profile involves a NIACS to set payload rates to zero, and then the ejectables deploy at payload 45º, 135 º, 225 º, and 315 º, in pairs. EDS utilizes a rocket motor for deployment, which allows the chemical disbursements to have point to point spreads of several kilometers. Chemical disbursements are set via the altitude event system.

5.11.5.2 Swarm Ejectable Deployment System

Swarm is a system for the deployment of instrumented ejectables that are like the form factor of the chemical EDS ejectables. The "Dallas" ejectables are the same 3.4 inches diameter and 13.2 inches in length, but with instruments in lieu of a chemical ampule. Swarm has been in development since 2018. The ejectables have included various instruments including PIP's, an ERPA, ion gauges, and others.

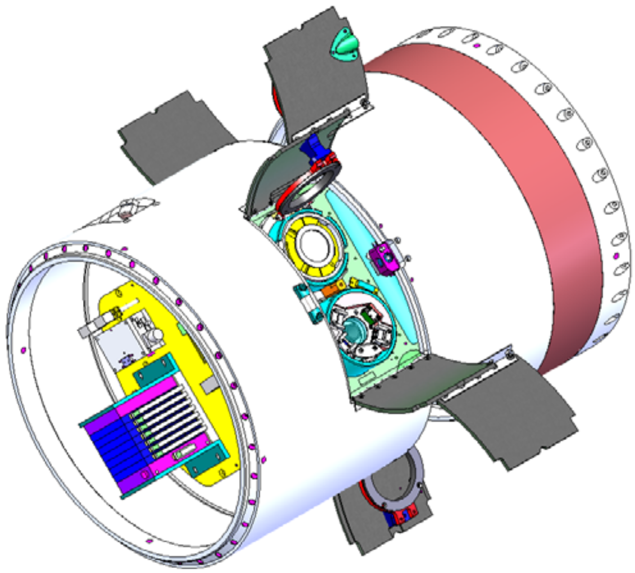


Figure 5.6: SWARM Section Assembly

For stability, the ejectables are ejected via a launch tube with rifling pins to induce a roll rate, which can be somewhat tailored for specific requirements. Spring launch tubes and rocket ejection can be utilized. Spring ejected Dallas ejectables can be equipped with GPS, currently rocket propelled ones cannot. As with EDS, there is a science portion of the ejectable on the front end with NSROC/ETD support electronics and power on the aft end. Data from the Dallas ejectables can be telemetered down to the ground or back to the main payload.

5.11.6 Vacuum/Water Sealing

Payloads may be designed with O-ring sealed sections and hermetic connectors to prevent entry and exit of gasses and liquids as required. Pneumatic hermetic feedthroughs have also been used in the past. Sections sealed for recovery against water typically weigh more than non-hermetic sections due to the need for more material for seals.

5.11.7 De-Spin Systems

In many cases, payloads must operate without the residual spinning motion imparted by the launch vehicle. Usually, the science instruments require very specific roll rates to operate or measure properly. A mechanical yo-yo de-spin system is typically used with sized weights attached to fly-away cables that are wrapped around the payload's circumference and unwind when released. NSROC's de-spin system is very reliable and de-spins payloads to the target roll rate +/- 0.25 Hz. Further tuning of the payload roll rate is accomplished by the on-board ACS to roll up or roll down from there.

5.12 Recovery Systems

The primary use of a recovery system is to retrieve the payload so it can be refurbished and flown again or to obtain scientific data such as from onboard data recorders or atmospheric samples. Land and water payload recovery are both possible on sounding rocket missions.

5.12.1 Land Recovery

Several different parachutes are used for land recovery; their principal characteristics are listed below in Table 5.12.1-1.

Table 5.12.1-1 Characteristics of Land Recovery Parachutes Type

Type	Maximum Recovered Weight (Pounds)
36.2 Foot Cruciform	750
50.3 Foot Cruciform	1000
56.8 Foot Cruciform	1250
64.4 Foot Cruciform	1500

5.12.2 Water Recovery

The water recovery system is rated for recovered payload weights up to 750 pounds and will provide buoyancy up to 333 pounds. At WFF, water recovery is performed by boat. A commercial source can be used to recover payloads that impact less than 100 miles offshore. The US Coast Guard is employed for payloads landing more than 100 miles offshore. Payloads with negative buoyancy margin must have flotation aids.

5.12.3 Recovery Aids

Recovery aids assist in the location of the payload to facilitate recovery. Commonly used recovery aids include the following:

- Canopy Color
- Reward Tags
- Flashing Strobe Lights
- Autonomous Rocket Tracker (ART)
- GPS Beacons

5.13 Attitude Control Systems (ACSs)

During a typical sounding rocket mission, the payload separates from the rocket and is de-spun well above the atmosphere. From de-spin until re-entry, typically a period of five to thirteen minutes, the ACS provides all control of the attitude of the payload section. To meet the objectives of the scientific mission, the ACS uses sensors to determine the payload's attitude, position, and velocity. The ACS also contains cold-gas thrusters which provide moments and control movement about all three of the payload's axes. The payload may be placed in one orientation for the duration of the exo-atmospheric flight or transition between multiple targets. Some ACSs can be controlled from the ground via a command uplink system allowing the onboard experiment to investigate targets of opportunity or to refine its pointing. Once the ACS has acquired a target, it requires very little force to maintain the payload orientation, so most of the scientific observations can be relatively undisturbed by the firing of thrusters. This has facilitated the acquisition of large amounts of previously unobtainable scientific data at a relatively low cost.

NSROC attitude control systems include coarse and fine control systems. The coarse control systems allow for pointing to inertial or magnetic targets at the degree level of accuracy. The fine control systems incorporate fine-pointing sensors to align with targets at an arc-second level of accuracy. The sensors associated with fine pointing are described in the sections of systems in which they are used.

NSROC selects the most appropriate attitude control system for a flight based on the requirements of the experiment. NSROC has four flight-proven pointing systems for a variety of applications. Two of these are coarse pointing systems:

- NIACS – NSROC Inertial ACS
- NMACS – NSROC Magnetic ACS

There are also two fine pointing systems:

- SPARCS VII – Solar Pointing Attitude Rocket Control System VII
- CACS – Celestial ACS

Table 5.13-1 Principal Characteristics of Attitude Control Systems

Table 5.13-1 Attitude Control System Capabilities	
NIACS	±2-3° Absolute Inertial Accuracy Spinning and Non-spinning Payloads
NMACS	±2-3° Magnetic Field Alignment Spinning Payloads Only
SPARCS VII	Solar Pointing Only ±10 Arcsec Accuracy in Pitch/Yaw ±1 Deg Accuracy in Roll Non-spinning Payloads only
CACS	±2-5 Arcmin without Star Tracker available on specific target, guide maneuver with tracker required to support this mode. ±1 Arcsec with Star Tracker (with Linear Thrust Module) Non-spinning Payloads only

5.13.1 NSROC Solar Pointing Attitude Rocket Control System (SPARCS VII)

The SPARCS VII is a precision attitude control system designed specifically to point the payload at the Sun during the exo-atmospheric portion of the flight. This ACS consists of 3 different optical sensor systems, 2 gyroscope systems, a magnetometer, a flight computer, and other electronics, a reaction control system using cold-gas pneumatics, and a battery power system. It can maintain any roll angle while pointing at any point on the Sun (not just the center), and it can be programmed to slew to different targets during the observation window. Furthermore, it can be controlled from the ground via a command uplink system to point to any target of opportunity or to refine the current pointing.

SPARCS has supported diverse scientific missions to map the sun's temperature, measure X-ray intensity, observe solar features, and capture other spectral data. Although SPARCS can theoretically support missions launched from anywhere, it has found a home at White Sands Missile Range due to its abundant sunshine, the dedicated test and integration facilities, and well supported payload recovery.

5.13.1.1 Capabilities

A typical solar mission enables SPARCS ~70 sec into the flight after the payload has cleared most of the atmosphere, separated from the motors, and de-spun to ~0.25 Hz roll rate. Because the scientific instruments point out of the aft end of the payload section, SPARCS needs to swing them through a large angle (as much as 180°) toward the Sun. This maneuver can take 40-50 sec depending on the initial conditions. Once it settles on a target, SPARCS can achieve a pointing accuracy (in pitch and yaw) better than 40 arc-sec[1] with a stability in the tenths of arc-sec. The roll orientation can be estimated and controlled to within 2°. Moving from one target on the Sun to the next can take 2-4 sec. After accounting for the maneuver time, a typical mission enjoys 5-7 minutes of quality, relatively disturbance-free, observation time.

SPARCS does impose constraints on the launch window, principally:

- The Sun must be at least 18° above the horizon for the optical sensors to isolate the Sun from the Earth albedo.
- For launches in the Northern hemisphere, the angle between the line-of-sight to the Sun and the Earth's magnetic field (called the eta angle) must be less than 165° to ensure roll angle acquisition. This requirement was designed to keep SPARCS well away from the scenario in which the magnetic field points directly away from the Sun in the Northern Hemisphere (eta=180°), which represents a singularity in its roll estimation algorithm (more on this later).

[1] The pointing accuracy depends on the system configuration and the target location. If video feedback is available for manual pointing corrections, SPARCS can be made to point at any target on the Sun within a few arc-seconds. Otherwise, the pointing accuracy varies with the target distance from the center of the Sun (~10 arc-sec at the center to ~40 arc-sec at the limb).

5.13.1.2 System Elements

Coarse Sun Sensors (CSS)

The CSS are a system of four sensors mounted along the circumference of the vehicle. Each sensor consists of two solar cells: the main cell and the bias cell. The main cell has a 180° field of view and sees both the Sun and the Earth albedo at any point in time. This cell protrudes from the bias cell in such a way that the former shades the latter from the Sun when the pointing error is < 30°. This allows the bias cell to measure only the Earth albedo, which can then be subtracted from the main cell output to improve the pointing accuracy.

One coarse sun sensor alone cannot tell the direction of the Sun, but the system of 4 can do so with an accuracy of ±1°. This system is used in the initial phase of acquisition (coarse mode) to swing the payload toward the Sun from ANY orientation.

Miniature Acquisition Sun Sensor (MASS)

The MASS is an analog optical sensor whose quadrant-detector produces output voltage signals proportional to the azimuth and elevation angles from its bore sight to the center of the Sun (called Sun angles for short). These are illustrated in the figure below:

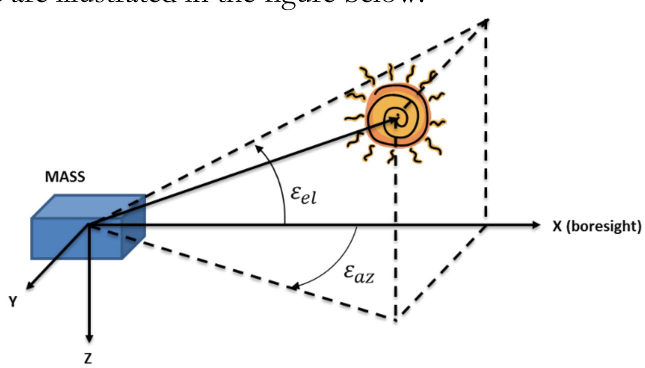


Figure 5.7: Miniature Acquisition Sun Sensor (MASS)

The MASS can measure these Sun angles with ±0.5° accuracy. It is mounted in the experiment section pointing aft, and its relatively small ±35° field of view effectively shields it from the Earth albedo when it is viewing the Sun. This sensor is used in conjunction with the CSS to enhance pointing accuracy in coarse mode.

Lockheed Intermediate Sun Sensor (LISS)

The LISS consists of 2 analog optical sensors: a ±20° field-of-view quadrant detector, and a ±10° field-of-view mode detector. These sensors are integrated into a physical package which is also mounted in the experiment section looking aft. SPARCS uses the mode sensor to switch out of coarse mode when the pointing error falls below 10°. As with the MASS, the LISS uses its quadrant detector to measure the Sun angles, and it can do so with ±10 arc-sec accuracy when it is calibrated. This measurement error is the main source of total pointing error for targets near the Sun center.

In intermediate mode and fine mode, SPARCS wraps control loops around the Sun angle measurements to point the LISS at a target on the Sun. This is illustrated in the figure below, where the payload needs to pitch up to reduce the current value of ε_{el} to its desired value of $\varepsilon_{el,c}$.

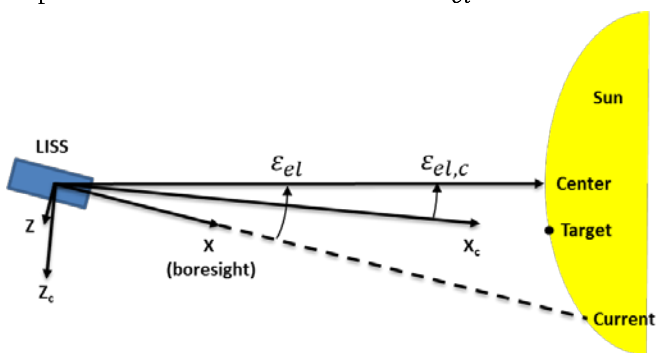


Figure 5.8: Lockheed Intermediate Sun Sensor (LISS)

Magnetometer

The SPARCS VII uses a miniature, 3-axis Bartington Model MAG-03MS mounted near the nose of the payload to estimate and control its roll orientation in intermediate mode and part of fine mode. Section 5.2.2 describes this magnetometer in more detail. This section describes how it is used in roll attitude determination and control.

Consider the situation when the payload is pointing at the Sun with an arbitrary roll attitude while the magnetic field vector H makes an angle eta with the Sun vector. H is shown decomposed into its longitudinal and transverse components H_x and H', respectively.

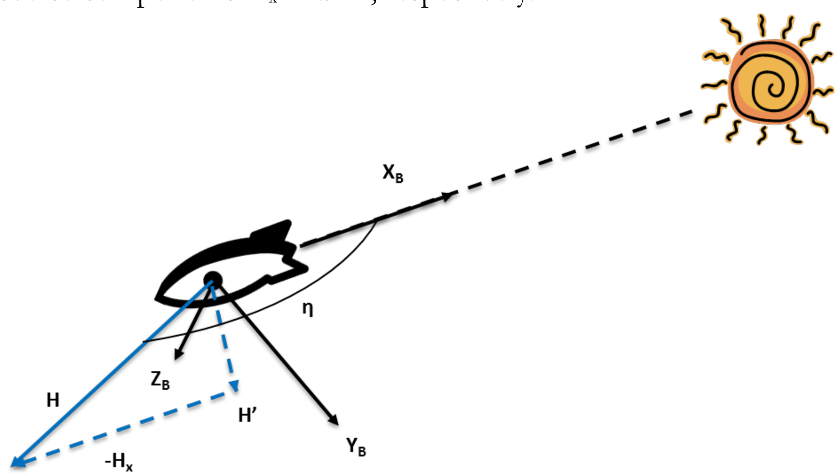


Figure 5.9: SPARCS VII Payload Pointing at the Sun with an Arbitrary Roll Attitude

Here is the same condition but looking along the payload axis at the Sun.

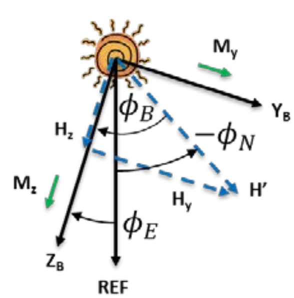


Figure 5.10: SPARCS VII Payload Pointing at the Sun Along the Payload Axis

The vector **H'** is shown at some other arbitrary orientation ϕ_N with respect to a reference axis (here shown as the South Heliocentric Pole). This angle will change during flight due to the spatial variation of the magnetic field. The payload roll orientation can be described by angle ϕ_E relative to the reference axis or by angle ϕ_B relative to the magnetic field. The magnetometers M_y and M_z are shown measuring the components H_y and H_z of the magnetic field, respectively.

A specification on ϕ_E can be turned into a specification on ϕ_B according to $\phi_{B,c}(t) = \phi_{E,c} - \phi_N(t)$, where ϕ_N can be characterized as a function of time by applying a geomagnetic model to the nominal trajectory.

The roll control loop estimates ϕ_B from the magnetometer measurements H_y and H_z according to $\phi_B = \text{atan2}(H_y, H_z)$. It fires the appropriate thrusters to regulate this angle to the desired value $\phi_{B,c}$. This is equivalent to regulating the absolute roll orientation ϕ_E to the desired value $\phi_{E,c}$.

Note that when the magnetic field $\mathbf{H}$ is aligned with the Sun vector (eta = 0 when $\mathbf{H}$ points along the Sun vector in the Southern hemisphere, or eta = 180° when $\mathbf{H}$ points opposite the Sun vector in the Northern hemisphere), it casts no shadow on the payload transverse plane (**H'** = 0). This leaves the magnetometers M_y and M_z to measure just noise, thus causing the estimation of ϕ_B to be completely inaccurate and resulting in loss of roll control. NSROC restricts the launch window to avoid these degenerate situations.

SPARCS uses the Bartington magnetometer in this scheme to estimate and control the roll attitude accurately to within 2°. Its main sources of error are: 1) magnetometer calibration errors, 2) magnetic disturbances not accounted for by the geomagnetic model, and 3) deviations from the nominal trajectory.

Humphrey Rate Gyro

The Humphrey rate gyro is a 3-axis analog strap-down gyroscope designed as a gimbal-less, simple, and sturdy rate sensor. SPARCS uses it for stability augmentation. NSROC is currently studying newer alternatives for this obsolete sensor.

Ring Laser Gyro (RLG)

The Honeywell GG1320AN01 Ring Laser Gyro is a single-axis digital rate gyro characterized by high stability (< 0.04 degrees/hour) and low jitter (< 0.01 degrees). It is mounted along the longitudinal axis in the SPARCS section to provide roll control in fine mode.

Pneumatic System

SPARCS generates the moments required to control the payload attitude by flowing gas through 8 thruster valves located throughout the payload. Four valves dedicated to controlling the pitch and yaw motions are located near the nose of the payload to maximize the lever arm to the center of gravity of the payload. The figure below shows valve #4 firing to produce a positive pitch moment.

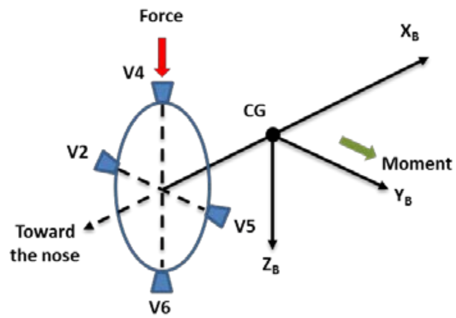


Figure 5.11: SPARCS with Vavle #4 Firing to Product a Positive Pitch Moment

Another set of four valves control the roll moment. The figure below shows the pair of valves V1 generating identical thrusts in opposite directions which act through the lever arm of the payload diameter to produce a positive rolling moment.

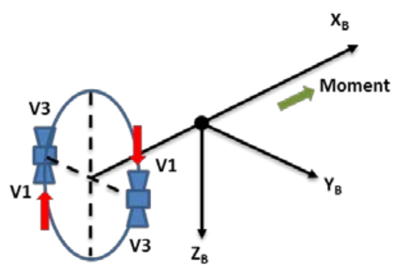


Figure 5.12: SPARCS with a Pair of Valves (V1) Generating Identical Thrust in Opposing Directions

The gas (usually Argon or Freon) is stored in an 880 in^3 tank which is initially pressurized to 5,000 psi. When enabled, the gas flows through a pressure regulator to arrive at the thruster valves at a controlled pressure, delivering a controlled thrust. SPARCS uses 2 pressure regulators and a relay to switch between the two at different times during operation. One regulator is set high for use in coarse mode, and the other one is set low for use in fine mode. The following table gives typical values of regulator pressure settings and angular accelerations:

		Coarse	**Fine**
Regulator Setting (psi)		600	50
Angular Acceleration (deg/sec^2)	**Pitch/Yaw**	2	0.2
	Roll	25	2

The thrusts generated by the fine pressure regulator are still too coarse for precision attitude control, so SPARCS fires opposite valves with slightly different durations to produce very small angular velocity changes in the desired direction. In the example above, V4 and V6 would fire an equal amount, but V4 would stay on slightly longer to generate a small net positive impulse along the pitch axis. This differential thrusting technique effectively turns a bang-bang control system into a continuous one at the expense of requiring more gas than a true continuous control system in which each thruster can generate a variable force.

5.13.1.3 Operation

SPARCS uses 3 modes to achieve the competing objectives of minimizing the maneuver time while achieving accurate and stable pointing to maximize the quality of the scientific data. These course, intermediate, and fine modes are described below.

Initially, **coarse mode** is dedicated to acquiring the Sun as fast as possible. This is done by using the CSS / MASS to locate the Sun and commanding the pitch/yaw thrusters to fire at full force to swing the payload toward it. Control action in roll consists of nulling the roll rate leftover from de-spin. Rate damping in all 3 axes is provided by the Humphrey rate gyro.

When the pointing error is reduced to ~10°, the Sun enters the field of view of the mode sensor of the LISS. Roll control uses the triggering of this sensor as the signal to switch to active roll position control with the magnetometer. SPARCS waits ~4 sec after this event for the rates to subside sufficiently to switch to **intermediate mode**. It decouples the CSS and MASS in this mode and uses the LISS to point at its first target on the Sun.

SPARCS stores the targeting information as desired values for ϕ_B, ε_{az}, and ε_{el}. During the alignment to the target, the three control loops act simultaneously to drive the current estimates of these three quantities to their desired values. This is illustrated in the figure below:

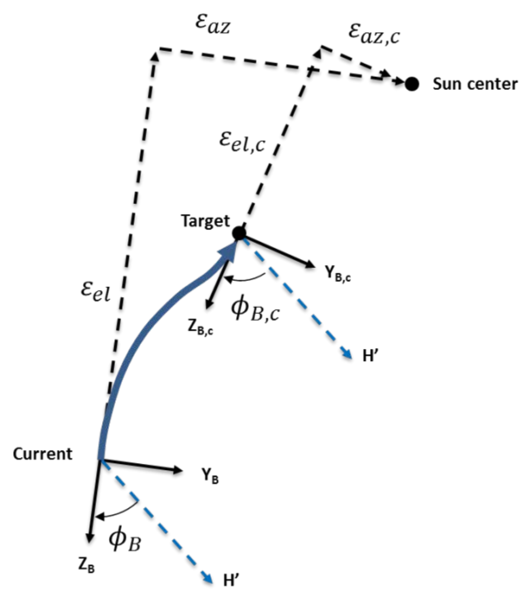


Figure 5.13: SPARCS Alignment to Target

SPARCS stays in intermediate mode for ~7.5 sec before switching to **fine mode**. Three things happen in this mode: 1) SPARCS switches to the fine pressure regulator and differential thrusting to better control the small motions required in this mode, 2) it switches to a larger set of control gains, and 3) it derives pitch & yaw rates from the LISS output signals to perform rate damping in these channels to control the pointing stability.

For missions requiring more control stability in roll (as well as in pitch & yaw), the system uses the RLG for roll control instead of the magnetometer. This change in roll control is initiated with a command from the ground. SPARCS updates its roll attitude by integrating the RLG output, which permits it to achieve sub-arc-second jitter performance. SPARCS can also visit other targets in this mode by receiving new targeting commands via the command uplink system. Any pre-programmed target may be sent at any time. Furthermore, SPARCS may be commanded to move specified amounts in all 3 axes to refine the pointing at any target. Thus, the integration of the command uplink system into the mission gives the experiment team maximum flexibility in targeting.

As the payload gets ready to re-enter the atmosphere, SPARCS disables the RLG and switches back to coarse mode with the coarse pressure regulator. It spins the payload back up to ~1 Hz by firing the roll thrusters at full force for 15 sec. This maneuver helps to distribute the heat build-up evenly around the payload. SPARCS also fires its pitch and yaw thrusters to de-pressurize the tank so that it is safe to handle during recovery.

5.13.1.4 Integration

Integration of SPARCS to the experiment section requires close cooperation with the experiment team mainly because the MASS and the LISS need to be installed in the experiment section and aligned with the science instruments.

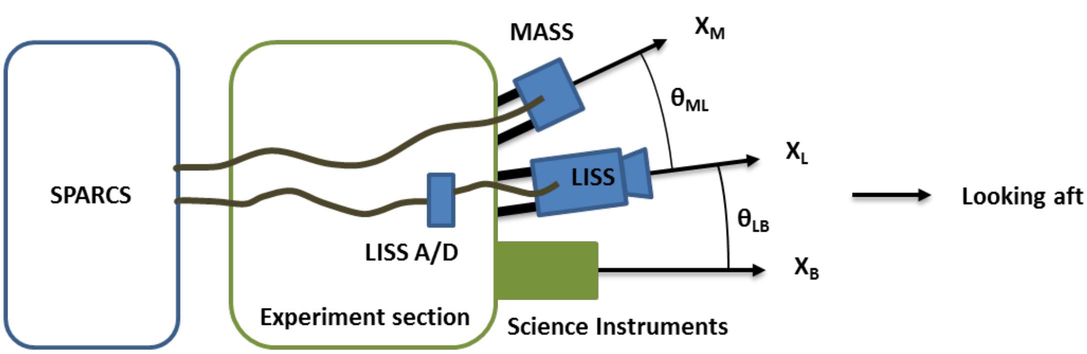


Figure 5.14: SPARCS Interfaces

The experiment team will be given mechanical drawings of the MASS & LISS soon after the mission initiation conference so that they can design locations and mountings for them in their section. Other requirements for these sensors include fields of view, reflectivity of nearby objects (the door must not reflect stray light into the LISS), and cabling. Because the LISS is used for fine pointing, the output signals are digitized near the source to minimize signal corruption. A separate A/D box is mounted in the experiment section near the LISS[2].

The experiment team takes delivery of these units when they arrive for integration. Although the experiment team is ultimately responsible for mounting these sensors and aligning them to the science instruments, they sometimes enlist the help of the ACS engineers in these efforts. Since the SPARCS points the LISS to the sun target, good pointing of the science instrument to the target requires good alignment of the LISS and science optical axis[3]. Therefore, a significant portion of integration is dedicated to aligning the LISS to the science instruments.

The LISS has a mirrored surface perpendicular to its optical axis that can be used in a heliostat experiment to characterize the alignment error angle θ_{LB}. This misalignment can then be minimized by shimming the 3 legs of the LISS like a stool. The MASS can similarly be aligned with the LISS, although this alignment is much less critical to the overall mission success.

One important area of collaboration between the experiment team and the ACS team during integration is the programming of the targets. The objective is to translate the target coordinates defined by the experiment team into the $(\phi_B, \varepsilon_{az}, \varepsilon_{el})$ format that SPARCS accepts. For example, the experiment team may specify a target by the (ϕ_E, W, N) coordinates defined in the diagrams below:

[2] There are plans to package the A/D electronics with the LISS soon.

[3] SPARCS is agnostic of the experiment systems on purpose so that it can serve a wide variety of solar missions.

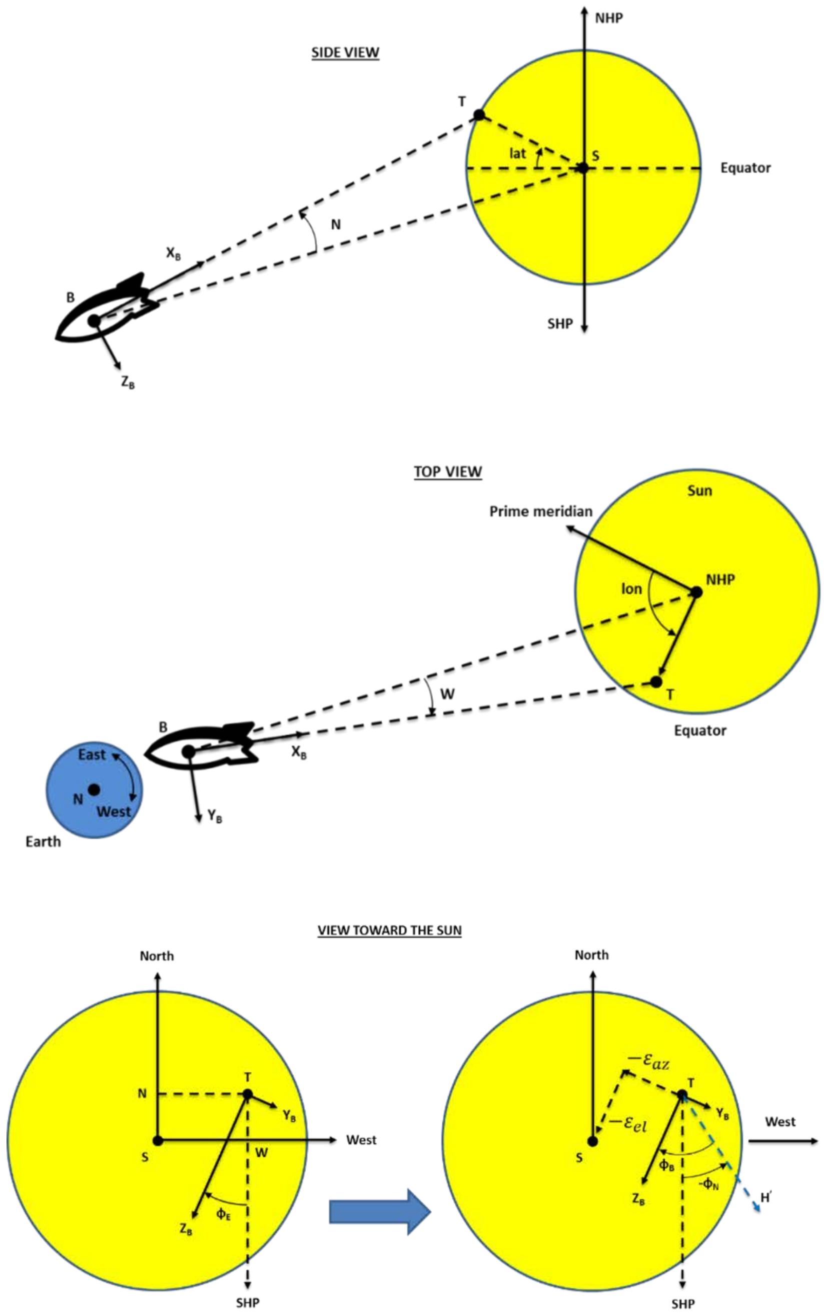


Figure 5.15: SPARCS Target Diagrams

Analysis of this geometry yields the following conversion:

$$\phi_B = \phi_E - \phi_N$$
$$\varepsilon_{az} = -W cos\phi_E + N sin\phi_E$$
$$\varepsilon_{el} = -N cos\phi_E - W sin\phi_E$$

There are many other ways to specify the target. For example, the (W, N) coordinates may be replaced by the (lon, lat) coordinates, the reference axis for the roll angle need not be the South Heliocentric Pole, or the new target may be specified by a series of moves from the last target. The experiment team is encouraged to use whatever systems suit them best if there is adequate communication with the ACS team to make sure the conversion to the SPARCS coordinates is correct.

5.13.2 NSROC Inertial Attitude Control System (NIACS)

The NIACS is an all-in-one digital control system that can align the payload to inertial targets. It has been used on a wide range of missions with coarse pointing requirements. These include ram air science missions, missions with ejectables that later align to the magnetic field, and a variety of other missions. The NIACS can align to an inertial target, the velocity vector, or the actual or predicted magnetic field vector.

5.13.2.1 Capabilities

Normally, the NIACS is enabled after yo-yo de-spin and payload separation are complete. After this, the NIACS follows a pre-programmed series of maneuvers based on the mission requirements.

The NIACS can provide absolute pointing error of less than 2° in all 3 axes. It has also demonstrated the ability to point the payload while spinning at roll rates as high as 4 Hz. During spinning control, the system is designed to measure error and align relative to the principal axis of the payload, not the physical centerline of the payload. This allows the system to minimize gas consumption, minimize coning, and naturally deal with dynamic imbalance and sensor misalignment.

The control provided by the NIACS during the science collection phase of the mission is highly mission dependent. Some flights have the ACS on for the entire flight. Others have the ACS turn on and off for specific windows of time. In other flights, the control changes based on the payload's altitude. The NIACS can also be programmed with a dead band which prevents the ACS from making corrections unless the error is greater than a specified value. The size of the dead-band can be chosen for each phase of the flight to improve the alignment during non-critical phases.

The NIACS can use between one and four 200 in^3 pressure tanks filled with either nitrogen or argon. It is also capable of using single-level or bi-level pneumatics.

The NIACS can provide a navigation solution – position and velocity information – in flight. If the payload includes a GPS receiver, the information from the GPS can integrated into the NIACS calculations. This can greatly improve the accuracy of the navigation solution.

The NIACS has been flown on 26 missions from its first flight in the spring of 2004 until May 2014 with a success rate of 96%. It has also been flown with wet-dry sealed sections allowing for water recovery of the payload.

5.13.2.2 System Elements

GLN-MAC

The GLN-MAC is the IMU used on-board the NIACS. It provides accelerations and angular rates to the control system. The GLN-MAC attitude solution is accurate to within 1°. The GLN-MAC is the only sensor used for attitude knowledge in the standard NIACS system. More details on the capabilities of the GLN-MAC can be found in Section 5.2.

5.13.2.3 MaNIACS

The MaNIACS is a variation of the NIACS which was first flown in August 2013. It contains a Honeywell HMR2300 three-axis magnetometer in addition to the regular NIACS components. The Honeywell magnetometer is described in Section 5.2.3. The addition of a magnetometer allows the payload to align with the true magnetic field as well as to inertial targets. The magnetometer is generally placed closed to either the forward or the aft end of the payload to reduce magnetic interference.

5.13.2.4 Integration

The integration process for the NIACS does not include any calibration between the GLN-MAC and the scientific instruments. When the MaNIACS is used, the payload must go through magnetic calibration prior to launch. This is a full payload test which is generally performed in each of the configurations in which the magnetometer will be used for attitude control.

5.13.3 NSROC Magnetic Attitude Control System

NMACS is used point a spinning payload along the Earth's magnetic field. This alignment can be with the field or against the field. NMACS can handle spin rates from 0.5 to 4 Hz and can stabilize the pointing error below 2 degrees.

NMACS uses two analog sensors to perform its job: the Bartington MAG-03MS60 3-axis magnetometer[4] to compute the pitch and yaw angles of the magnetic field with respect to the payload frame of reference, and the Systron Donner QRS-116 gyroscope to perform rate damping as it controls these angles to their desired values. A newer version of NMACS, called Digital NMACS or DNMACS, replaces these analog sensors with digital ones, namely the Honeywell HMR2300 3-axis magnetometer[5] and the SiIMU02 MEMS Inertial Measurement Unit.

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[4] See Section 5.2.2 for more details.

[5] See Section 5.2.3 for more details.

Due to its small size and simplicity, NMACS represents an elegant control solution for missions that fit within the scope described above. This system has been flown on 26 missions from its first flight in the summer of 2003 until May 2014. However, it is being flown less and less in favor of NIACS or MaNIACS[6]. Specifically, customers that are flying a NMACS application frequently require the attitude product from the GLN-MAC. In this case, the MaNIACS provides a better total solution. If there is no attitude knowledge required, the NMACS or DNMACS is a lighter weight and less expense solution.

5.13.3.1 Operation & Capabilities

As with all NSROC control systems, NMACS uses cold-gas pneumatics to provide the reaction forces needed to control the payload attitude. Depending on the length and the complexity of the mission, NMACS may use one to four 200 in^3 tanks of Nitrogen or Argon gas pressurized to 5000 psi to provide the control. Most missions flow the gas through one pressure regulator to generate a standard thrust level - this is preferred for simplicity.

After payload separation, NMACS is enabled to follow its pre-programmed timeline which varies according to mission requirements. Some missions may use a dead band which de-activates the thrusters if the pointing error is below a threshold. This allows for disturbance-free measurements while the payload is aligned with the target. The thresholds are typically 10 deg, but they can be chosen over a wide range to suit the experiment's needs. Other missions may choose to turn the control off after the initial alignment, then turn it back on after a time to update the pointing.

NMACS can maintain the pointing error below 2 degrees while in active control mode. During spinning control, the system is designed to measure error and align relative to the principal axis of the payload, not the physical centerline of the payload. This allows the system to minimize gas consumption, minimize coning, and naturally deal with dynamic imbalance and sensor misalignment.

5.13.3.2 Integration

Success of an NMACS mission depends critically on a well-calibrated magnetometer. Toward this end, the magnetometer location can be chosen almost anywhere in the payload to minimize the magnetic interference of the rest of the system. Calibration is performed with the payload completely integrated and with as many systems turned on as possible to account for as many stray fields as possible.

However, NMACS does not attempt to perform alignments with accuracies as high as SPARCS VII (solar missions) or CACS (celestial missions). Therefore, precision alignment with the scientific instruments is not required. The calibration results are not explicitly used for the NMACS. The purpose of the test is to assess whether the selected location of the magnetometer is sufficiently magnetically clean for control. In the event of an issue, this test will also be used to possibly find a more suitable location for the magnetometer.

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[6] NIACS does not have a magnetometer, but it does have a full navigation solution which it can use to align the payload to the geomagnetic model. And MaNIACS is a version of NIACS that does incorporate a magnetometer, so it can perform the same mission as NMACS and more.

5.13.4 NSROC Celestial Attitude Control System

The Celestial ACS is used to align sounding rocket payloads to celestial targets. This attitude control system is used for flights investigating targets which can either be acquired and tracked with a star tracker or pointed at by using nearby celestial targets as a reference. Previous CACS missions have studied comets, planets, and the Earth's atmosphere in addition to stellar targets.

The CACS uses a GLN-MAC gyro and an ST-5000 star tracker to determine its attitude. The pneumatics system is available with three thrust configurations: bi-level, tri-level, and linear. Since its debut in May 2006, this ACS has flown on 24 missions as of May 2014 with a success rate of 96%.

5.13.4.1 Capabilities

The Celestial ACS combines an ST-5000 star tracker with a GLN-MAC fiber-optic gyro and a specially designed control loop to achieve better accuracy and stability than its predecessor, the Aerojet Mark VI-D. Unlike many of the NSROC attitude control systems which are generally self-contained, the CACS is not contained within a single section. The pneumatics and electronics deck of the celestial ACS are normally located forward of the center of gravity. The system also includes remote pitch and yaw nozzles which are in the ORSA at the forward end to provide a larger lever arm. Additionally, the star tracker is in the experiment section at the aft end of the payload where it can be aligned with the experiment's detector. The electronics for the CACS can be located as far as away from the tracker camera head as necessitated by the mission. This allows for greater flexibility in the placement of the camera relative to the science instruments in the payload.

This system can point to up to 20 targets in a single flight. However, the time available to spend on each target depends on the number of targets and the distance between them. As a result, most missions have only two or three targets. Additionally, the capabilities of the ST-5000 star tracker place some restrictions on the timing of the launch and the location of the targets. For the star tracker to function properly, the sun must be at least 25° below the horizon. The star tracker is also unable to determine an attitude solution if the target is too close to the horizon. This does not preclude targeting objects close to the horizon, but it does mean that all pointing in that region must be done using only inertial control.

The Celestial ACS is capable 2-5 arc-minutes absolute pointing accuracy. This improves to 1-2 arc-seconds pointing accuracy when the command uplink system is used. The CACS can provide various levels of stability depending on the requirements of the mission. Using bi-level control, the jitter rate is around 10 arc-seconds per second. This can be improved to 2 to 3 arc-seconds per second with tri-level control or to less than 1 arc-second per second using the linear thrust module (LTM). With each improvement in steady state control, the weight of the ACS increases.

Traditionally, celestial missions have mainly flown out of White Sands Missile Range due to the ease of recovery. However, other launch locations may be considered.

5.13.4.2 System Elements

ST-5000

The ST-5000 is a next generation, low-cost star tracker. It consists of two-parts: an electronics stack and a sensor head or camera. This instrument is capable of multi-star tracking anywhere in the sky. It also has a lost-in-space (LIS) capability. This allows it to determine an attitude solution from anywhere in the sky within 7 seconds. The ST-5000 was developed by University of Wisconsin – Madison.

GLN-MAC

The GLN-MAC is the IMU used on-board the Celestial ACS. It provides accelerations and angular rates to the control system. More details on the capabilities of the GLN-MAC can be found in Section 5.2.

Linear Thrust Module (LTM)

Most pneumatics systems used in the control systems have only two states: on and off. Additional levels of control can be achieved by using multiple discrete pressure settings. The linear thrust module (LTM) provides finer control by allowing the pressure level to be varied linearly. This system is used for the fine thrust level to support missions with strict pointing and stability requirements. These missions also use the LN-251.

LN-251

The LN-251 is a strap-down 3-axis IMU which is much more accurate than the GLN-MAC. It is used in addition to the GLN-MAC and in conjunction with the LTM to support missions with strict pointing and stability requirements.

Pneumatics

The Celestial ACS uses a fine pointing separable pneumatics system (SPS). It contains a single 395 in^3 pressure vessel. For missions requiring more gas, 1 or 2 200 in^3 piggyback tanks can be added to the system.

5.13.4.3 Operation

The CACS does have its attitude initialized prior to lift-off. However, this action is not its final source of attitude. The ST-5000 takes a snapshot of the sky at turn-on and compares it to a database of the sky. It then uses a lost-in-space (LIS) algorithm to determine its initial attitude. Thereafter the star tracker provides position information relative to its previous attitude. The CACS combines the information from all available sensors to determine the required control. After large motions, the system does perform a new LIS and the attitude is re-initialized.

Although the timeline is mission dependent, the CACS generally follows a similar timeline for all missions. In this timeline, the ACS turns on around 65 seconds after launch and the initial pointing process takes approximately 40 seconds. To move between targets after the initial pointing process has been completed can take up to 20 seconds. However, this time is highly dependent on the location of the two targets that it is moving between.

Command Uplink System (CUS)

The Command Uplink System for the Celestial ACS was based on the existing CUS for the SPARCS VII system. The experiment team is responsible for providing video data to be telemetered down to the ground station. The CUS displays this video with a set of crosshairs and other overlays pertinent to the experiment. The customer may send real-time commands to the CACS by manipulating the crosshairs to refine the pointing or move to another target altogether. The command uplink system also provides several buttons which can be used to transition from one planned target to the next. This can be used to ensure adequate observation time before switching targets. If desired, the star tracker video can be used as a source for CUS for relatively gross motions. More information on the command uplink system can be found in Section 5.18.5.

5.13.4.4 Integration

Since the Celestial ACS provides arc-second pointing capabilities, the science team must work closely with the ACS team during the integration process to ensure that the star tracker camera and the scientific detectors are precisely aligned. The star tracker is mounted in the experiment section.

Before vibration testing, dark room measurements of the alignment between the detector and the star tracker are made. Additionally, the offset between the mass model and the actual system is determined. After vibration testing, the same measurements of the alignment are taken again. This allows for an estimate of how much the alignment may change during launch. Once this is complete, the actual star tracker is co-aligned with the scientific detector.

For payloads which are using the command uplink system, the payload is next placed in a cradle to simulate the command uplink environment. This simulation is to verify the CACS and CUS operating as a system. Perhaps more importantly, this simulation provides an environment for the science team to practice the in-flight operations and decision making necessary for a successful mission.

5.13.5 Command Uplink System

The command uplink system evolved to serve the needs of solar and celestial researchers to interact with and control their payloads in real-time during the missions. Fundamentally, the CUS allows personnel to send two types of commands to the payload: 1) commands to turn on or off relays and other systems in the experiment section and the attitude control section, and 2) commands to the ACS to refine its attitude or move to another target altogether. This puts the human in the loop for missions that full automation is not practical and to address the small misalignments that will result from the powered flight.

The CUS engineer and experiment personnel interact with the payload through a graphics user interface, a sample of which is shown below:

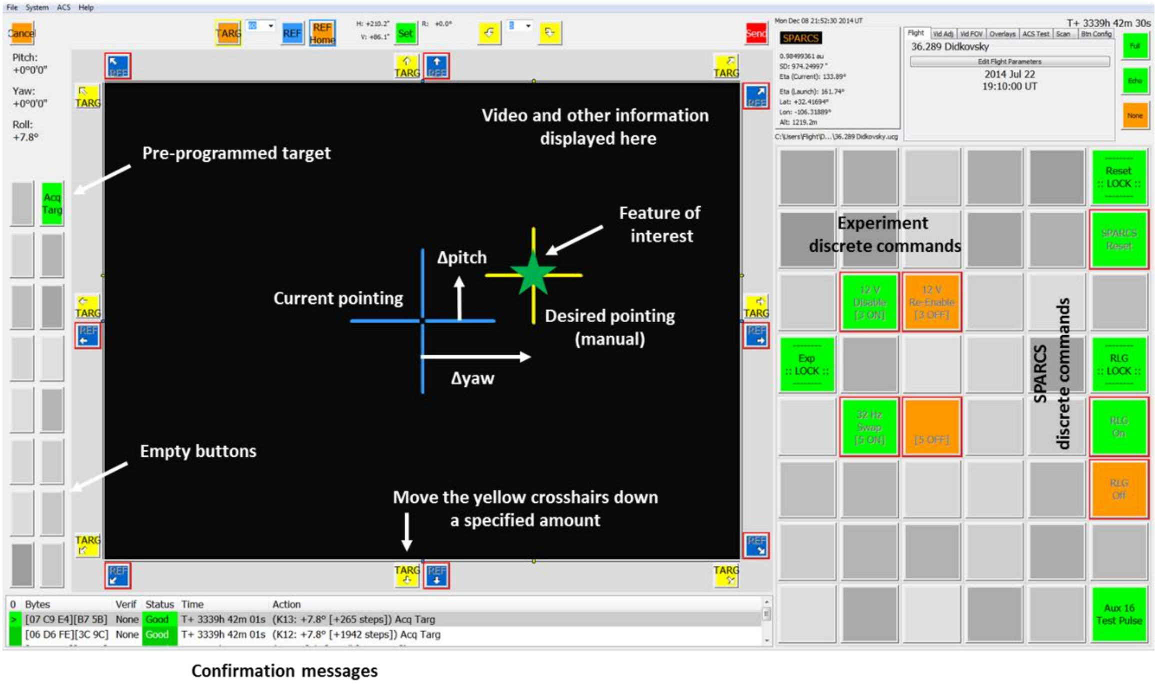


Figure 5.16: Graphical User Interface

This GUI was used in a SPARCS (solar) mission that flew in July 2014. The panel of buttons on the right usually hosts discrete commands for the experiment section and the ACS. The experiment team has the option of routing all, some, or none of their discrete commands through the CUS. Some customers prefer to stand at this station to control the pointing, so it makes sense to have some experiment discrete commands at their fingertips. The discrete commands for the ACS can be seen on the far right – these are usually operated by the CUS engineer.

In addition to the discrete commands, the CUS can send targeting information to the ACS. The targeting command is a set of angles (r_c, p_c, y_c). The desired roll angle (r_c) is specified relative to a roll reference axis, and the desired pitch and yaw angles (p_c & y_c) are relative to a pointing reference. A target programmed in this way is called an absolute target because it can be approached from any initial conditions. This is illustrated in the angle-angle picture below:

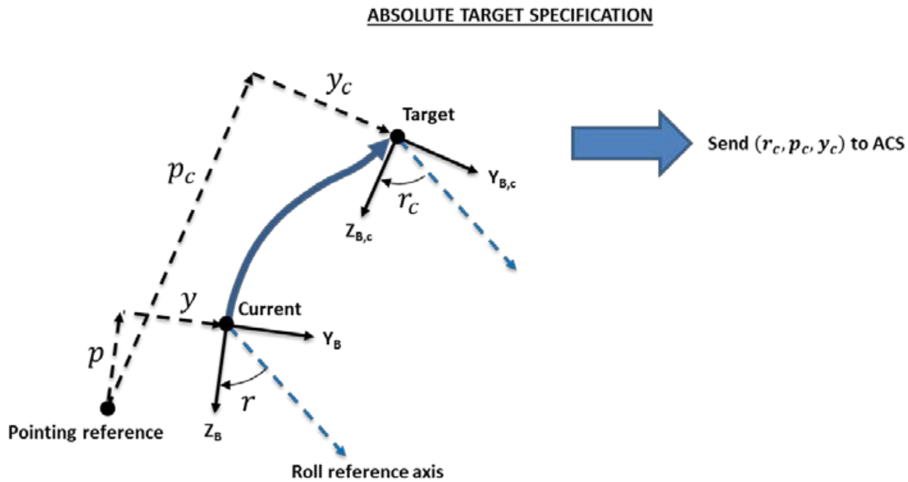


Figure 5.17: Absolute Target Specification

Note that the pitch & yaw specifications depend on the roll specification. For SPARCS (solar), the pointing reference is the Sun center, and the roll reference axis is the local magnetic field. SPARCS wraps its control loops around the magnetometer-derived roll measurement and the LISS-derived pitch & yaw measurements to drive them to their desired values. For CACS (celestial), both references are the solution to the lost-in-space algorithm which initializes the attitude. The roll, pitch, and yaw estimates are provided by the GLN-MAC-based inertial navigator aided by the ST-5000 star tracker.

Sometimes it is more convenient to specify a target relative to the current attitude. This is called a relative target, and it may be programmed as a set of angle increments $(\Delta r, \Delta p, \Delta y)$. The CUS keeps track of all the commands sent, which allows it to estimate the current attitude[7]. It uses this information to convert the relative coordinates to absolute coordinates before sending to the ACS. This process is illustrated in the figure below:

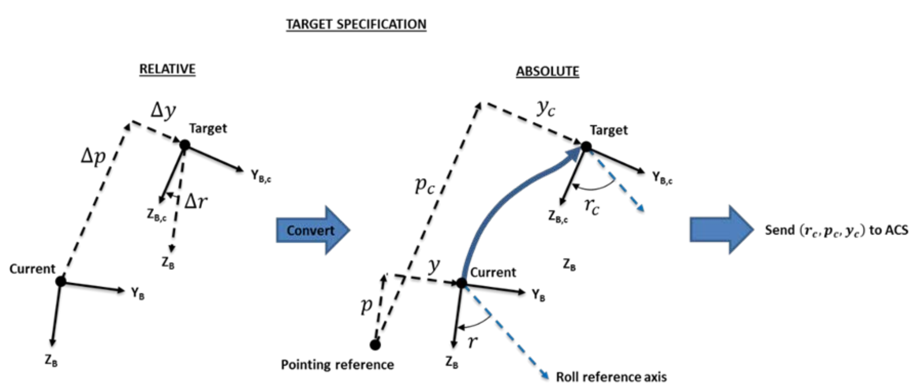


Figure 5.18: Target Specification

[7] In fact, a targeting command sent may or may not be received and executed by the ACS. The CUS avoids getting out of synch with the ACS by waiting for a successful echo of the command before updating the attitude.

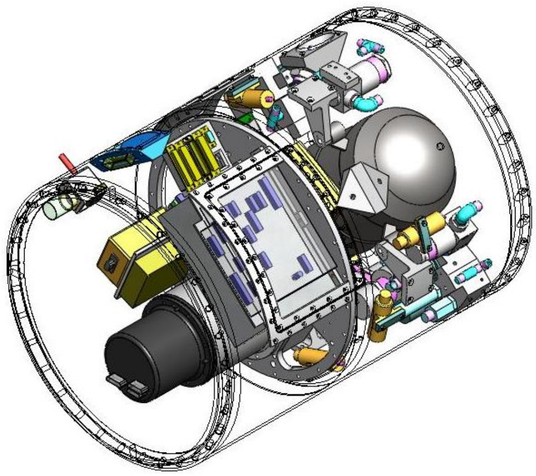
The panel of buttons on the left of the GUI is usually reserved for the pre-programmed targets. The lone button labeled "Acq Targ" represents the acquisition target with absolute coordinates $(r_c = 7.8°, p_c = y_c = 0)$. Other targets may be likewise programmed as absolute or relative targets. Absolute targets can be useful as "clean slates" that reset the ACS attitude regardless of history. On the other hand, relative targets can be useful to propagate the pointing adjustments from one target to another. A target may even be programmed multiple times: once as an absolute target, and other times as a target relative to other targets. This gives the experiment team maximum flexibility in targeting.

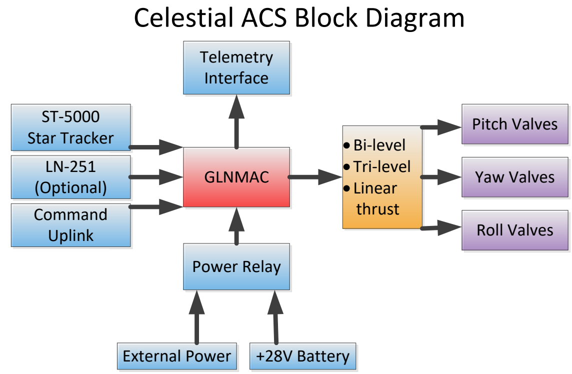
For missions that have video or can convert the science data into video, the center panel will display the video images underneath the crosshairs. The blue reference crosshairs can be calibrated to correspond to the pointing of the science instruments. In steady state, this pointing may be offset from the feature of interest (e.g., a Sunspot) due to a variety of factors. For example, the experiment team may decide to investigate an opportunistic phenomenon which is offset from the current pointing, or the offset may have resulted from a shift of the instruments during launch. Regardless of the source of the offset, it can be nulled by commanding the ACS to move a certain amount in the appropriate direction.

Placing the yellow crosshairs on top of the feature of interest allows the CUS to count the vertical and horizontal pixels to the blue crosshairs and convert them into the pitch and yaw offset angles. These maneuvers can be sent to the ACS as a new target in the same manner as a relative target. Alternatively, the customer may click on a yellow arrow at the periphery of the panel to instruct the ACS to move a specified amount in the desired direction. These are effective ways to refine the pointing of the science instruments down to the arc-second level.

Missions without video feedback can still use the CUS to refine the pointing if the offset can be quantified by some other means (e.g., spectrometry data). In this case, the experiment team determines the offset from the real-time telemetry data and communicates it to the CUS engineer so that he/she can send the appropriate commands to the ACS. In any case, mistakes in pointing corrections during the mission can be minimized by close cooperation between the two teams and extensive testing during integration.

NSROC Celestial ACS (CACS)





GENERAL CHARACTERISTICS

Sensors:
Standard: ST-5000 from the University of Wisconsin at Madison; Gimbaled LN-200 with Sandia Miniature Airborne Computer (GLN-MAC)
Optional: LN-251 fine IMU package

ST-5000 Specifications
Update Rate……………………………10 Hz
Visual Magnitude Range………………-1 to +8
Noise Equivalent Angle………………0.8 arcsec
Number of Stars Tracked………………1-32
Field of View……………………………5.4˚ x 7.4˚
Mean Solution Time……………………7 sec

Celestial ACS Performance Specifications
Data Output Rate (SDLC)…………………400 Hz
ACS Sampling Period (Async)……………50 Hz
Average rate to 1st steady state……… 3.7-5.4°/sec
Nominal Angular Accelerations (°/sec2)
Lateral (Coarse | Inter | Fine)…...3.2 | 0.14 | 0.05
Roll (Coarse | Inter | Fine)………7.5 | 2.5 | 0.2

Nominal Dimensions
Diameter ………………………………17.26 in
Height ……………………………………24-38 in
Weight…………………………………90-130 lbm

Pneumatics System
Tank Capacity…………………...395, 595, or 795 in3
Typical Tank Pressure……………………5000 psig
Regulated Pressures:
Coarse……………………………………300-700 psi
Intermediate……………………………50-200 psi
Fine………………………………………5-50 psi
Linear Thrust……………………………5-150 psi
Nominal Impulse, Argon @ 5,000 psi:
395 in3……………………………………297 lbf*sec
595 in3……………………………………447 lbf*sec
795 in3……………………………………597 lbf*sec

Electrical System
Operating Voltage…………………………28 V
Batteries………………………..24 cell @ 4.5 A-hr
Pneumatics Solenoids……………30 **Ω**, 0.9 A (each)
GLNMAC ……………………………………… 0.9 A
ST-5000…………………………………… 0.75 A
LN-251…………………………………………… 0.8 A
Telemetry……………Analog and async serial data

Steady State Pointing………..Linear | Bi-Level
Absolute Pointing Error…..< 2 arcsec | < 25 arcsec
Jitter ……………………….< 1 arcsec | < 15 arcsec

Section 6: Environmental Testing Policies

This section summarizes the Environmental Testing policies for the NASA Sounding Rocket Program. This content is largely an excerpt of the NSROC Environmental Testing Manual (ME40280) which can be accessed through NSROC's document control system.

6.1 General Requirements

All tests, whether conducted on components or payload systems, must be initiated by a T&E Test Request NSROC engineers are responsible for test requests for sounding rocket missions.

6.1.1 Qualification Testing

New component designs are required to undergo design qualification testing. These tests expose items to environments that are more severe than the expected payload environment. This ensures that the design is robust and that there is high confidence that component failure will not occur during a mission. Components subjected to qualification test levels are not used as flight hardware. Limited or modified qualification testing is used on a case-by-case basis, depending on a component's application but is not typical. New component designs are qualified using a qualification procedure; the results of which are recorded within a qualification report.

6.1.2 Acceptance Testing

Qualified component designs and <u>all</u> payload assemblies (new or re-fly) must undergo acceptance testing, which exposes test articles to the environments that mimic those experienced during a mission. These tests are the standard for determining the robustness of a component or payload.

6.1.3 Customer Testing

Customers are encouraged to test their components to NSROC standards prior to integration. If a PI is unable to conduct these tests due to equipment or facility limitations, the NSROC facilities may be utilized. It is recommended that customers report to the Mission Manager any environmental testing completed prior to delivery. This information is required if the customer requests a waiver for a test normally conducted by NSROC.

6.1.4 Test Plan

The payload Mechanical Engineer is responsible for developing a test plan, with team concurrence, for a particular payload and its related components. This entails the following: determining exactly which tests are required, confirming a test schedule per the Mission Manager's mission schedule and with the Environmental Testing and Evaluation Group, generating test requests for each test, and writing procedures for all hazardous and/or complex tests. Most deployment tests are written using a configurable deployment test procedure. Additional tests may be required by the Instrumentation Engineer or Power Engineer.

6.2 Testing Equipment and Capabilities

NSROC has two principal testing facilities. The primary facility is located at the NASA Wallops Flight Facility (WFF) in Wallops Island, VA; the other is at White Sands Missile Range (WSMR) in White Sands, NM. Both facilities have the equipment necessary to perform the following tests:

- Mass Properties Measurements
- Static/Dynamic Balancing
- Vibration Tests
- Bend Tests
- Thermal and Thermal Vacuum Chambers
- Magnetic Calibrations

In addition to these assets, WFF is also equipped with a spin deployment chamber and a centrifuge machine. A spin balance facility for balancing rocket motors is located on Wallops Island.

6.2.1 Mass Properties Measurement Systems (WFF and WSMR)

The Environmental Testing and Evaluation lab at WFF is equipped with a Space Electronics updated, Airdyne Mark 8mass properties measurement system (Figure 6.2.1-1). This unit is used for measuring center of gravity (CG) locations and moments of inertia (MOI) on sounding rocket subsystems and payload bodies. Important technical data include:

- Maximum test article weight: 5,000 lb.
- Maximum CG height above the table: 120 in.
- CG Sensitivity 2 lb.-in   CG Linearity = 1.0%
- MOI Sensitivity = 2 lb.-in   MOI Linearity = 0.15%

At WSMR, the mass properties measurement system is used to perform all static and dynamic balancing of sounding rocket payloads.

Figure 6.1: Airdyne Mark 8 Mass Properties Measurement System at WFF

6.2.2 Static and Dynamic Balancing Machines (WFF & WSMR)

At WFF, a Gisholt Rocket Balancing Machine is used to balance sounding rocket payloads (Figure 6.2.2-1). This machine's specifications are listed below.

- Max. payload weight = 1,500 lb.
- Max. height of CG above table = 120 inches
- Measurement accuracy = 2.0 oz-in^2 at 180 rpm

At WSMR, balance operations are completed using the mass properties measurement system, described above

Figure 6.2: Gisholt Rocket Balancing Machine at WFF

6.2.3 Shakers (WFF and WSMR)

There are four Ling Electronics shakers used for component and payload vibration tests at WFF (Figure 6.2.3-1) and two at WSMR. The following table summarizes some technical information on the shakers.

Table 6.2.3-1 NSROC Shaker Specifications

Shaker	B340	B335 (x2) WFF	B395 WFF	B335 (x2) WSMR
Rated Force Sine (lb.)	30,000	18,000	6,000	18,000
Rated Force Random (lb. rms)	30,000	18,000	5,750	18,000
Frequency Range (Hz)	5-2,000	5-3,000	5-3,000	5-3,000
Maximum Displacement Peak-Peak (in.)	1.0	1.0	1.0	1.0

The B340 can be rotated to mate with a TEAM Corp. model 482 sliding table so that it can be used for both thrust axis and lateral vibration tests. This table has the following specifications.

- Max. pitch moment capacity = 1,200,000 lb.-in.
  One of the B335 units at WFF is connected to a TEAM Corp. model 1830 sliding table while the other is kept in the thrust axis position. This arrangement facilitates performing three-axis vibration tests in a timely manner, without having to rotate the shaker. Both B335 shakers at WSMR are also equipped with the TEAM 1830 table, which has the following specifications.

- Max. pitch moment capacity = 240,000 lb.-in. The B395 is a smaller shaker mostly used for component level tests at WFF. Both the WFF and WSMR test facilities are equipped with 11 in. cube fixtures so that tests can be performed on small components in all three axes by mounting the test article in different orientations. At the engineer's or customer's request, sensors can be mounted on any part of the payload to monitor its response. WFF has 16-channel capability and WSMR has 8-channel capability.

Figure 6.3: Ling Electronics B335 Thrust Axis Shaker

6.2.4 Vacuum Chambers (WFF and WSMR)

WFF has three sealed chambers capable of evacuating to approximately 10^{-6} torr. Two of these chambers are mainly used for performing corona checks on subsystems that utilize high voltage components (PV/T, Tenney Space Jr.). The third can be used as a thermal-vacuum chamber and as an ultra-clean environment for testing other components that require contaminant-free environments (Tenney Space Simulation System). The table below summarizes technical data on these chambers. Chambers appear in Figure 6.2.4-1.

Table 6.2.4-1: NSROC Vacuum and Thermal Vacuum Chamber Specifications

Manufacturer	**PV/T Inc.**	**Tenney Space Simulation System**	**Tenney Space Jr.**
Inside Dimensions (ft. dia. x ft. lg.)	7x12	2x2	1.2x1.0
Minimum Pressure (torr)	2×10^{-5}	3×10^{-8}	7.5×10^{-8}
Temperature Range (°C)	N/A Heat lamps used if needed	-73 to +125	N/A

Figure 6.4: PV/T Vacuum Chamber (left) and Tenney Space Simulation System Thermal Vacuum Chamber (right) at WFF

The PV/T Chamber is also equipped with a mass spectrometer for outgassing measurements. In addition, WFF is equipped with several leak detectors and portable vacuum systems. Specifications for this equipment are available upon request. They include:

6.2.4.1 The Portable Vacuum System.

This is a 91 cm (36 in) unit with a 10.1 cm (4 in) flange adaptable to a similar mating surface for the purpose of pumping a vacuum on any sealed container. Pumping is accomplished by a 5 cm (2 in) diffusion pump in conjunction with a roughing pump and a cold trap (LN_2, Freon or water). The vacuum capability is 10^{-7} torr or lower. There is no specific limitation as to the size of test chambers; however, the pumping capacity restricts the volume for high altitude simulation. Various other portable systems are available that employ cryosorption and cryogenic pumps.

6.2.4.2 The Vacuum Leak Detector – Helium Mass Spectrometer

This is used for leak detection; two models are available: a Varian Model 938-41 Leak Detector employs a diffusion pump and can detect leaks as small as 10^{-9} cc/sec. An Ulvac Model DLMS-531 employs a turbo pump and can detect leaks at the rate of 3 x 10^{-10} cc/sec. There is no specific limitation as to the size or type of items to be leak tested. Typical items tested include sealed payload units, pressure bottles and vacuum chambers.

6.2.4.3 Vacuum Bell Jars

The Vacuum Bell Jar is a cylindrical vertical chamber measuring 45.7 cm (18 in) in diameter by 91.4 cm (36 in) high. The bell jar is equipped with a 0.14 m3/min (5 cfm) mechanical pump. This system is used to test altitude switches and small components up to an altitude of 200,000 ft using a mechanical pump. A second Bell Jar utilizing a Turbo Pump can be used for "clean" items and is capable of 10^{-8} torr vacuum. This Turbo Pump is portable and can be detached from the Bell Jar and attached to a payload to maintain vacuum.

WSMR has two sealed chambers capable of evacuating to approximately 10^{-6} torr. These chambers are also used for performing corona checks on subsystems that utilize high voltage components. Normally used with dual Welch 1397 oil sealed mechanical fore-pumps, fittings also allow the use of Cryo-trap equipped Turbo pumps. Other uses have been Nozzle flow separation tests into a vacuum. The table below summarizes technical data on these chambers. WSMR can support the varied customer needs found in the field environment through unique system configurations, adapters, and pumping setups. WSMR also has a Helium Leak Test System available.

Table 6.2.4-2 WSMR Vacuum and Thermal Vacuum Chamber Specifications

Manufacturer	NRL	PSL	Notes
Inside Dimensions (in. dia. x in.)	20x36	31x51	Aluminum
Minimum Pressure (torr)	1×10^{-6}	1×10^{-6}	
Temperature Range (°C)	N/A	N/A	
Pump Type	Turbo Model #3133C	Turbo Model #3133C	With Welch 1397 fore-pumps

6.2.5 Bend Test Fixtures (WFF and WSMR)

Every sounding rocket payload is subjected to a bend test to determine the overall stiffness of the body. This information is used by the Flight Performance Group to verify payload stability during flight. The bend test fixtures at WFF and WSMR consist of a base plate mounted to the concrete floor and a pneumatic (WFF) or motor driven (WSMR) linear actuator mounted to a steel I-beam pillar. The pistons are equipped with load cells, which are used to measure and control the applied load. The aft end of the payload is fastened to a fixture, and the actuator's position along the pillar can be adjusted to the proper height on the payload being tested. A theodolite is used to accurately measure the tip deflection of the payload as the actuator applies lateral loads in both directions. Lateral deflections can be measured along a test article's length or height, and deflections on either side of a joint can be used to calculate a joint's stiffness or compliance.

Figure 6.5: Payload Undergoing Bend Test at WFF

Technical data for the systems is listed below.

Table 6.2.5-1 NSROC Bend Test Fixture Specifications

Facility	Maximum Load (Actuator or Load Cell)	Maximum Actuator Height .	Accuracy of Deflection Readings
WFF	+/- 5,000 pounds	21 feet	0.005 inches
WSMR	+/- 1,150 pounds.	21 feet	0.005 inches

6.2.6 Spin Deployment and Separation Equipment (WFF)

Payloads with deployable booms, nose cones, doors, etc. can be tested for proper function using the spin deployment and separation chamber at WFF. The rotary table can spin a payload to a rate of 20 cps while withstanding an imbalance of up to 3000 ft-lb, 5 ft. above the table surface. The chamber is equipped with a heavy-duty Kevlar® tarp around the rotary table for catching deployed components. Video cameras mounted on the chamber walls for recording and timing the deployment events. Pyrotechnic release devices can be activated by connecting lead wires through a 20-channel slip ring that allows the table to rotate while maintaining electrical continuity.

This equipment is also used to do operational spin tests on payloads.

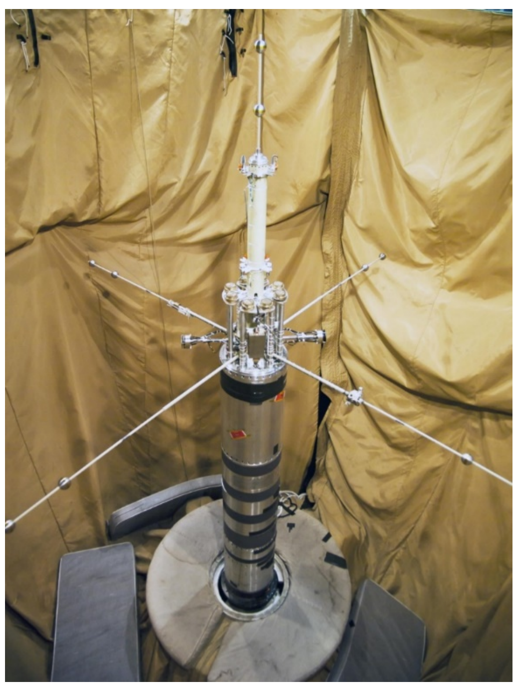


Figure 6.6: Spin Deployment Chamber at WFF

The WFF test facility is also equipped with a portable spin table that is used for special deployment tests. These include inverted deployments, during which the spin table is suspended from the high bay bridge crane, and horizontal deployments.

6.2.7 Centrifuge Machine (WFF)

Figure 6.7: Ideal Aerosmith Centrifuge at WFF

An Ideal Aerosmith Model 1068-2 centrifuge machine is used for component acceleration tests at WFF. It can achieve up to 1000 g acceleration at a radius of 10.5 in. It has 8" of clearance between the 3' diameter rotary table and the cover. The unit has a 108-channel slip ring with 3-amp capacity on each channel. Various D-Sub connectors, ranging from 9pin to 37pin, are available for connections to the test item and supporting GSE. There are also 2 RF connections that support up to 4 GHz and 18 GHz, both channels utilizing SMA connectors.

6.2.8 Magnetic Test Facility (WFF & WSMR)

At WFF, this facility is used to conduct magnetic calibration of magnetometers on sounding rocket payloads and to perform functional tests on magnetic attitude control systems. When required, magnetic calibration tests are done - generally for all payloads with magnetometers except those in which the magnetometers are used as roll or yaw indicators. The testing equipment consists of a three axis, 40 ft. square Braunbek system which can cancel the effects of the earth's magnetic field and generating a test field in any direction. Technical data are listed below.

- Resolution = 10 nanotesla
- Field magnitude = 0-65,000 gamma

The Magnetic Test Facility (MTF) was developed to support the magnetic testing capabilities for NASA at Wallops Island. The MTF consists of the computer, control software, power supplies, racks, computer desk, analog instrumentation chassis, reference magnetometer, and relay box. The coil system consists of a 40 foot "Square Braunbek" design to provide the facility with a 6-foot diameter homogeneous field.

Figure 6.8: Magnetic Test Facility at WFF

The MTF software is designed to interactively operate the three-axis magnetic coil system. The software provides the operator with the ability to control the magnetic coil system either manually or through standardized automated tests. Automated test modes include Zero Bias, Linearity, Cosine Law response, Axis Displacement, and Rotating Field. Other unique tests can be performed if required.

Three channels of analog data, typically corresponding to sensor X, Y, and Z outputs, can be digitized to 14-bit resolution, and are sampled, averaged, and stored in computer files for each applied field. The stored data sets are text files which are converted and plotted in Microsoft Excel ® for easy data analysis. Payload RF data can also be sent to F-10 for data recording and display. Consult Tables 6.2.8-1 and 6.2.8-2 for details about the equipment and control capabilities at Wallops.

At WSMR, the Magnetic Calibration Facility has the following capabilities:
- 3-axis Station Magnetometer digital readout in milligauss
- 10-foot diameter Helmholtz coil with adjustable vector from zero to > one earth field in any axis.

Table 6.2.8-1: Instrumentation Available at the WFF Magnetic Test Facility

Item	Function	Specifications	Model
Proton Magnetometer	Calibration	Range: 20K-120K Gamma Resolution: 0.01 Gamma System Accuracy: 0.2 Gamma GSM-19	GEM
Triaxial Fluxgate Magnetometer	Test Instrumentation	Range: ±100K Gamma Resolution: 3 Gamma Orthogonality: 25 Arcmin	EMDS SDM-313
Triaxial Fluxgate Magnetometer	Ambient Sensor (outside)0	Range: ±100K Gamma Resolution: 3 Gamma Orthogonality: 25 Arcmin	EMDS SDM-313
Payload Magnetometer	Test Instrumentation	Range: ±100K Gamma Resolution: 3 Gamma Orthogonality: 1 Degree	Bartington Mag-03MRN
Theodolites	Alignment	Resolution: 20 Arcsec Dicarlo	Theo020B
RF Horn Antenna	Data Receiving Freq.	Range: 1-18 GHz Gain: 7 dB Model 3115	Emco
RF to Fiber-Optic Transmitter	Data Conversion Freq.	Range: .1-5 GHz Watts: 6.4 mW 3450A-20	Ortel

Table 6.2.8-2: Magnetic Test Facility Specifications

Physical Dimensions:	
Access Opening	8'8" H x 7'5" W
Static Field Environment:	
Magnitude (each axis)	±100K Gamma
Step Resolution	±3.7 Gamma
Stability	±10 Gamma/minute for first 30 minutes ±3 Gamma/minute after 60 minutes
Homogeneity	0.02%, 6 ft. spherical diameter
Dynamic Field Environment:	
Magnitude	+60K Gamma
Frequency	10 Hz, although 10 Hz to 100 Hz @ 1K Gamma has been performed
Turntable	4' Diameter
Coil Orthogonality	1.8 Arcmin, Calibrated on 9/27/96
Fields	Earth, 0-15 Volts DC, 0-25 Amps Test, (3-Axis) 50 Volts AC, ±8 Amps Gradient, 15 Volts DC, 6 Amps

6.2.9 Spin Balance Facility (WFF, Wallops Island)

On Wallops Island, there is one Gisholt Balancer (in V-45), like the one described in Section 6.2.2. The facility is also equipped with a vibration analyzer, which is used to detect and measure mechanical vibrations during balancing. This Spin Balance Facility can perform balancing of hazardous systems.

6.2.10 Facility Clean Rooms (WFF & WSMR)

6.2.10.1 Wallops Flight Facility

The NSRP has access to a Clean Room and Clean Tent in Bldg. F-7; across the street from F-10. Payload hardware and GSE can be transported to the building by truck. There is a clean tent inside of the clean room. The room has a crane. NSROC Mission Management will coordinate access to this room if requested.

Figure 6.9: Clean Room at WFF, Bldg. F-7

6.2.10.2 White Sands Missile Range

The VAB science room is 40'x57' with 14' drop ceilings and is a clean work area. There are no single access doors to the outside. The HVAC system has an adjustable fresh air supply to create higher pressure in the science room compared to adjacent rooms, it is also equipped with an industrial humidifier to maintain humidity above 30%. Air filtration uses Merv-11 filters and the HVAC blowers run continuously. The room is industrially cleaned once per year, all horizontal surfaces are wiped down after each mission or monthly, floor is swept and mopped after each mission or monthly.

- The Science room has two soft wall clean tents (one 10' x 20' and one 10' x 28') both met ISO Class 7 (Fed Standard 10,000) during the last test cycle.
- ESD work areas are established and maintained by NSROC/SMA in the main science room and inside each clean tent.
- Temperature, humidity, and oxygen monitors are installed in the main science room and the clean tents

6.2.11 Optics Capabilities (WFF & WSMR)

6.2.11.1 Capabilities at WFF

Activities involving optics at WFF revolve around testing and integrating the ST-5000 star tracker into the CACS (celestial) missions. Capabilities include:

Star simulators in a dark room: a field of stars can be simulated and used to calibrate and test the star tracker. This is done by reflecting light from fiber optic cables off a 20-inch parabolic mirror. The brightness can be adjusted, and collimation is achieved by placing the emitters at or near the focal point of the mirror. A spatial resolution of 10 arc-sec can be achieved by controlling the separation of the emitters. The 3 simulators can be wheeled around on carts and positioned at different locations in the room to simulate different parts of the sky.

Figure 6.10: ACS Air-Bearing in the Dark Room

- Articulated Cradles: The payload can be made to look at different parts of a star field by moving it on an articulated cradle in the dark room. Each cradle has two-axes servo motors that rotate the payload left & right or rotate up & down. With payload on the cradle (approximately horizontal), this motion produces payload yaw and pitch, respectively. Payload roll motion is not supported. The ACS valve commands can be linked to the servo motor commands so that closed loop control with command uplink can be practiced.
- Air-bearing: The ACS can also be mounted on a large bearing supported by a layer of air that allows it to rotate freely in 3 dimensions under control of its thrusters. This can be setup in conjunction with the star simulators in the dark room to simulate a CACS mission.

6.2.11.2 Capabilities at WSMR

WSMR supports both SPARCS VII (solar) missions and CACS (celestial) missions requiring optical instruments. WSMR maintains a **dark room** with one star simulator to support CACS missions. Although this room can support motion tests using a borrowed articulated cradle from WFF, it is not equipped to support air-bearing tests.

The rest of the discussion pertains to optics capabilities relating to solar missions. An **optics lab** is dedicated to maintaining, testing, and calibrating the MASS and LISS sensors. The essential equipment in this lab is listed below:

- A sun simulator reflects light from a special incandescent bulb at 1/100th the intensity of the Sun off a 15-inch parabolic mirror to generate collimated light to exercise the sensors.
- A rotary table to rotate the sensors with respect to the sun simulator. The rotation can be controlled in angle or in speed.
- An optics-grade granite table supports the rotary table and other equipment.
- A German equatorial mount for the LISS gain ATP.
- Ground support equipment including computers, data acquisition cards, power supplies, cables, etc. This equipment controls the rotary table and gathers and stores the sensor data for analysis.

Activities requiring sunlight such as testing and aligning optical sensors can be done indoors in the **heliostat room**. The essential equipment in and outside of this room is listed below:

- A heliostat or sun tracker sits immediately outside of the room, which faces South to maximize sun exposure. Its 29-inch flat mirror reflects sunlight into the heliostat room through a large window to illuminate the payload. About 50% of the light intensity makes it through atmospheric absorption and other losses to reach the payload. The heliostat control system uses a sensor to determine the direction to the Sun and commands servo motors to rotate the mirror in pitch and yaw to track it. This setup can be modified to allow the LISS to control the heliostat mirror directly in closed-loop tests. If a command link is installed in the payload, pitch/yaw closed-loop dynamic tests can be performed.
- Sometimes the beam of light reflected off the heliostat mirror is too small to illuminate the entire payload. This commonly happens in winter when the Sun is low. These situations can be remedied by using a secondary mirror in conjunction with the heliostat. A new 29-inch flat mirror has been procured, and a custom mount for it will be finished by April 2015.
- The heliostat room houses a 5 ft x 8 ft granite table, which can be floated to maximize stability for critical alignment tasks, and a clean tent to shelter sensitive payload sections.

When inclement weather precludes the use of the heliostat, the team may choose to do the sensor alignments and related tests with an autocollimator in the **integration lab**. This instrument emits collimated light from an incandescent bulb through its 16-inch aperture, like the sun simulator. But it also has the capability to receive and measure reflections of this light off the surfaces of the sensors and other objects placed in its path.

6.3.1 Static and Dynamic Balance

The payload mechanical engineer must first determine which payload configuration(s) must be balanced (or measured for imbalance) to ensure mission success. The mechanical engineer must also provide the test technician(s) with the stations of the upper and lower balance planes for placement of balance weights. The payload launch configuration must then be measured for Total Indicator Runout, which is the amount of lateral misalignment of the payload measured at the nose tip. The payload shall then be balanced such that the criteria in Table 6.3.1-1 are met. It is important to ensure that dynamic balancing is not performed at a spin rate equal to the payload's first natural frequency. This is done to avoid pitch-roll coupling, which can damage both the payload and the balancing equipment.

Table 6.3.1-1 Static and Dynamic Balance Specifications

Tip Indicator Runout (in.)	Static Imbalance (oz.-in.)	Dynamic Imbalance (oz.-in.^{2})
< 0.25	< 300	< 20,000
< 0.40*		

* For Payloads Exceeding 250 inches

These specifications can be relaxed if the payload team, specifically the Flight Performance Engineer, the Mechanical Engineer, and the Mission Manager agree that the mission requirements will still be met. If required, the Mechanical Engineer will design flight weights to be installed internal to the payload.

A check balance is required for all payloads after flight balance weight have been installed, especially for spinning science configuration payloads. The acceptable residual imbalance for this operation is defined by the ACS Engineer. Payloads with numerous deployments or control configurations may take additional time to nullify imbalance.

6.3.2 Bend Test

The Flight Performance Engineer will calculate the maximum expected bending moment at the aft joint of the payload (payload to motor interface) and predicted tip deflection under this load. The Flight Performance Engineer must then supply the Mechanical Engineer with the lateral load necessary to achieve 125% of the bending moment or 50% of the rated capacity of the joint; whichever is greater. This load shall be applied near the forward end of the payload, usually at the first major joint. It is important to bend the payload about more than one lateral axis, especially if the payload has multiple doors and/or large doors. After the tests are complete, the Mechanical Engineer will provide the Flight Performance Engineer with the maximum tip deflection of the payload for each bend test configuration This data will be used in the flight profile analysis and will be presented at the MRR. Bend tests are also used to measure the compliance of non-standard joints or joints that have been modified significantly.

6.3.3 Mass Properties

Every payload must undergo mass properties measurements in both the launch and the control configurations and any other configurations that are critical during the mission, e.g., re-entry, booms stowed, booms deployed, etc. The following properties will be measured.

- Weight
- Center of Gravity
- Roll Moment of Inertia
- Pitch Moment of Inertia

6.3.4 Vibration

The launch configuration of every payload must complete vibration testing to be considered acceptable for launch, this is an acceptance level test. Before any full level tests are conducted in each axis, a thrust ½-g Sine Survey must be performed to determine payload natural frequencies. Trickle tests are conducted for tests in the lateral axes. This information can be used to limit vibration input and protect payloads and testing equipment from excessive loading. The Mechanical Engineer must determine which vibration tests are required according to the flow chart in Figure 6.3.4-1.

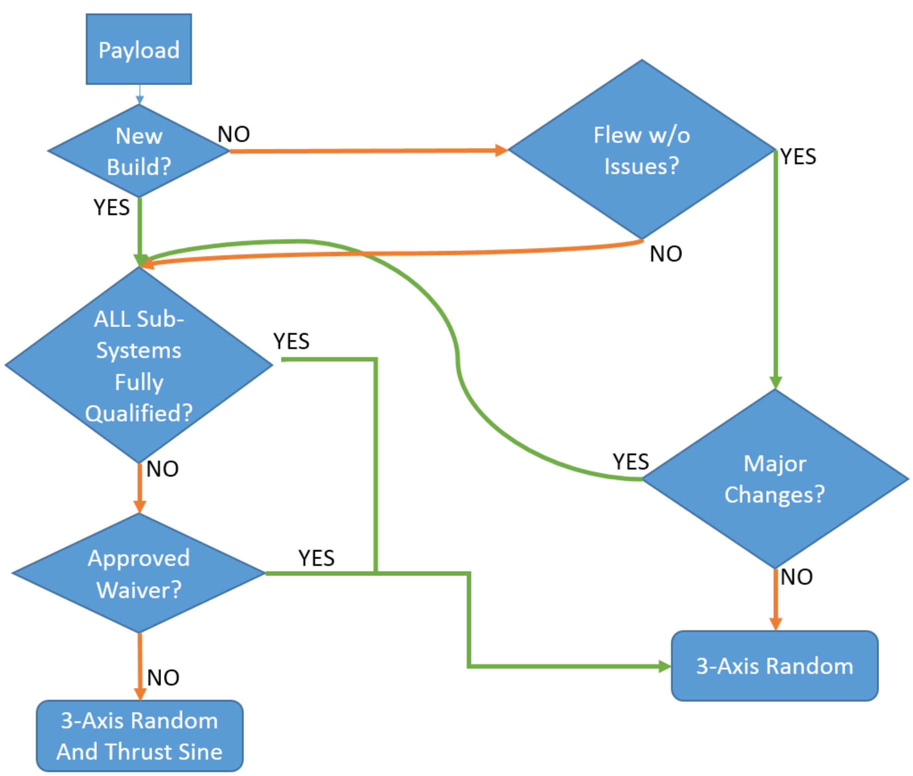


Figure 6.11: Vibration Test Level Flow Chart

It is the responsibility of the Mechanical Engineer to provide the Environmental Testing group with the vibration test levels for a particular payload according to Table 6.3.4-1. It is important to heed the footnote below Table 6.3.4-1 concerning payload bending during lateral vibration.

Table 6.3.4-1 Vibration Test Levels for New Payload Designs

	Vehicle Level One	Vehicle Level Two
SINE	Sweep Rate: 4 oct./min. Test Profile: 3.0 in./s 10-144 Hz 7.0 g 144-2000Hz **THRUST AXIS ONLY**	Sweep Rate: 4 oct./min. Test Profile: 3.84 in./s 5-24 Hz 1.53 g 24-110 Hz 3.50 g 110-800 Hz 10.0 g 800-2000 Hz **THRUST AXIS ONLY**
RANDOM	Duration: 20 sec./axis Thrust Axis Spectrum: 10.0 grms 0.051 g^2/Hz 20-2000 Hz Lateral Axis Spectrum: 7.60 grms 0.029 g^2/Hz 20-2000 Hz	Duration: 10 sec./axis Spectrum: 12.7 grms 0.01 g^2/Hz 20 Hz 0.10 g^2/Hz 1000 Hz (on 1.8 db/oct. slope) 0.10 g^2/Hz 1000-2000 Hz **SAME IN ALL AXES**
TEST INFO	**LEVEL 1 VEHICLES** Single Stage Improved Orion Terrier MK12 – Improved Orion Terrier MK12 – Malemute Terrier MK12 – Lynx	**LEVEL 2 VEHICLES** Single Stage Black Brant Terrier MK12 – Improved Malamute Terrier MK70 – Improved Orion Terrier MK70 – Malamute Terrier MK70 – Improved Malamute Terrier MK70 – Lynx Terrier MK70 – Oriole Black Brant IX Black Brant X Black Brant XI and XIa Black Brant XII and XIIa

Note: Input to payload during lateral sinusoidal vibration must be limited during first bending mode via dual control accelerometer at CG of the payload. This is done to avoid exceeding the maximum bending moment at the base of the payload.

6.3.5 Waivers

If a customer wishes to exclude or modify one or more of the above payload level tests, he or she must submit a request in writing to the Mission Manager. Another member of the mission team may submit the request on behalf of the customer. The request shall include an explanation for the exclusion or modification and any other pertinent details. All requests must be reviewed and approved by the Mechanical Engineer, the Mission Manager, and by the NSROC Engineering Manager.

6.3.6 Test Times

The following guide may be used for estimating the time required for each test.
Static and Dynamic Balance (check, balance, and re-check) 1 – 3 days

- Deployment ½ -1 day (per test)
- Vibration ½ - 1 day
- Bend Test ½ - 1 day
- Mass Properties ½ - 1½ days

6.4 Component Testing

A sounding rocket component is any self-contained functional unit comprised of two or more mechanical and/or electrical parts. This includes, but is not limited to, transmitters, batteries, receivers, gyroscopes, etc.

In general, components that are new designs and/or that have never been launched before are required to undergo testing. See ME40280 for more information. The following is a list of typical tests that are conducted on sounding rocket components.

- Thermal Cycling
- Vacuum and Thermal Vacuum
- Vibration and Shock
- Acceleration
- Deployment and Separation
- Magnetic Calibration

Section 7: NASA/GSFC/WFF Safety Policy and Responsibilities

This Section provides an overview of GSFC/WFF safety policies and associated organizational responsibilities, operational procedures, and flight and ground safety rules. Safety is a major consideration in all sounding rocket operations, from the earliest planning stages through launch, data recovery and mission close-out. Safety requirements draw upon the unique and exhaustive experience of the Goddard Space Flight Center's Wallops Flight Facility. As an experimental lab under the National Advisory Committee for Aeronautics, its later role as a research flight facility, and in its current role as a GSFC facility, Wallops has more than 65 years of experience in sounding rocket operations.

The policies, procedures and references in this Section apply to all mission activities conducted and managed by GSFC/WFF and to all NASA employees, NSROC (NASA Sounding Rocket Operations Contract) contractor personnel, NSRP customers, and support personnel. Missions conducted at other launch ranges (such as WSMR) will comply with local range requirements, including requirements that are more restrictive. The policies and procedures described and referenced in this Section will be considered the minimum requirements for all personnel. PIs should discuss safety considerations with the Mission Manager and consult references for detailed design, engineering, operational and procedural guidance.

Note: Department of Defense (DOD) personnel adhere to DOD rules; however, they must also adhere to GSFC/WFF policy and guidelines while at WFF.

NASA/GSFC/WFF and NSROC publications provide detailed safety policies to raise awareness of existing or potential hazards and provide appropriate control techniques:

- Goddard Space Flight Center (GSFC) Wallops Flight Facility Range Safety Manual (GSFC-STD-8009) for Goddard Space Flight Center (GSFC)/Wallops Flight Facility (WFF), dated June 5, 2019. NASA Safety Standards such as NASA-STD-8719.12 Safety Standards for Explosives, Propellants, and Pyrotechnics, NPR 8715.3D NASA Safety and Health Program, NASA-STD-8719.17 NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS), GPR 8710.7C Cryogenics Safety and NASA-STD-8719.9 for Lifting Devices Safety
- NASA East/West Range Safety Requirements of AFSPCMAN 91-710
- NSROC Safety and Health Plan QS51007, NSROC Quality Manual QS47413

The Mission Oversight Monitor (MOM) or the Mission Manager (MM) will provide the latest version of these documents.

7.1 Safety Policy

Safety plays an essential role in NASA's pursuit to expand frontiers in aeronautics and space. Health and safety are our highest priority. We will not compromise the safety and health of our people and property nor harm the environment. We are working to achieve zero mishaps in the NASA workplace, keeping in mind that every employee's safety and health, both on and off the job, is our concern.

The NASA Agency Safety Initiative (ASI) is aimed at strengthening NASA's capabilities so that safety permeates every aspect of NASA work. By fully implementing this initiative and incorporating safety and health principles and practices into NSROC's daily decision-making process, we will maintain our position of leadership by maintaining the safety and occupational health of our work force and the safety of the products and services we provide.

The ASI establishes the NASA safety hierarchy - the order we used to prioritize our safety efforts. The safety hierarchy is:

- Safety for the public; we absolutely must protect the public from harm
- Safety for astronauts and pilots; they expose themselves to risk in high hazard flight regimes
- Safety for employees; we owe it to our employees to provide them with a safe and healthful workplace
- Safety for high value equipment; we are stewards of the public's trust

By focusing on the safety of NASA's mission and operations, we will improve quality and decrease cost and schedule.

GSFC/WFF will conduct all ground and flight operations with a degree of prudence appropriate for highly hazardous operations and in accordance with sound technological principles. To achieve this objective, three cardinal principles apply:

- It is impossible to eliminate human error or system failures; therefore, safety planning and precautions are established to cope with the resulting hazard.
- One preventive measure is insufficient for hazard control. Planning procedures or system requirements shall be established such that a combination of at least two extremely unlikely events must occur to cause an accident.
- Safety is an integral function of each supervisor's responsibilities.

For any mission where these policies cannot be met, the risk will be analyzed and presented in a Risk Analysis Report (See Section 8.4 below), with a recommendation for approval or disapproval, to the Director of Suborbital and Special Orbital Projects Directorate, Code, Code 800.

Again, safety is *THE* priority for sounding rocket operations. It is inherent in all policies and procedures and an integral part of the GSFC/WFF Quality Assurance and ISO 9001 programs. Responsibility for any given mission is shared by all parties involved.

7.2 The Range Safety Organization

The Director of GSFC is responsible for safety at WFF. The Director of SSOPD, who represents the Director of GSFC, has established a programmatic safety organization and designated safety responsibilities for other organizational elements. The references above describe the safety responsibilities for each organizational component. The Wallops Safety and Mission Assurance Division (Code 390) is responsible for implementing the range safety policies, criteria, and operations at WFF. The Safety Office is the principal safety coordinator for GSFC/WFF sounding rocket missions performed at other ranges.

7.2.1 Safety Responsibilities of the Mission Manager (MM)

The Mission Manager is the primary safety planning point of contact for NSRP customers. The MM will provide to the Safety Office, no later than 90 days prior to the scheduled launch date, the following data for all new or modified launch configurations:

- Flight Requirements Plan
- Nominal flight trajectory data
- Dispersion data
- Vehicle physical characteristics
- Rocket motor information
- Vehicle structural limitations
- Aerodynamic data
- Wind compensation methods
- Aeroelastic and flight loads analysis
- All hazards associated with the launch operation.

For standard vehicle configurations and payloads, nominal flight trajectory data, dispersion data, and wind compensation methods should be provided two months prior to the scheduled test date. The MM reviews vehicles and payloads to assure criteria and range safety standards are met and refers all exceptions to the Safety Office (Code 390).

Approved safety procedures for vehicles and payloads meeting all range safety standards are published in the Operations and Safety Directive for all campaigns and WFF operations and in the Flight Requirements Plan for other ranges.

7.2.2 Safety Responsibilities of the Customer

It is the customer's responsibility to become fully acquainted with the safety policies and criteria set forth in the Goddard Space Flight Center (GSFC) Wallops Flight Facility Range Safety Manual (GSFC-STD-8009) for Goddard Space Flight Center (GSFC)/Wallops Flight Facility (WFF), dated 09 June 2022 as well as the other safety materials cited in the introduction to this Section.

PIs must design payload systems to fully conform to the policies and criteria established by the GSFC/WFF; and must identify any vehicle or payload systems and/or operational requirements that cannot meet the GSFC/WFF and NASA safety policies and criteria.

PIs will provide data to the MM, either through conferences or formal documentation, for safety review. The data will include information on payload systems, descriptions, and requirements of the project operations. PIs must also submit requests for any waivers from prescribed procedures before arriving at the GSFC/WFF. Appendix E details the data required in formal documentation. For additional information see Goddard Space Flight Center (GSFC) Wallops Flight Facility Range Safety Manual (GSFC-STD-8009) for Goddard Space Flight Center (GSFC)/Wallops Flight Facility (WFF), dated 09 June 2022.

In the event of a mishap, a NASA Mishap Report, Form 1627, will be initiated and forwarded to the WFF Safety Office, Code 390. The Safety Manager or the Operations Safety Specialist will take reasonable and proper actions to limit or prevent injury to personnel and damage to or loss of equipment and property. Management and safety personnel will issue instructions for any investigation and reports required through the MM.

PIs will be required to provide information requested to fully understand the cause of the mishap and develop recommendations for any subsequent actions.

7.3 Ground Safety Plan (GSP)

The ground safety goal of GSFC/WFF is to minimize the risks to personnel and property involved in the handling, preparation, and launch operations for launch vehicles and payloads. A Ground Safety Plan will be prepared by the Safety Office, Code 390, prior to any launch operations conducted by GSFC/WFF at WFF or other ranges. This plan covers operating variables involving the storage and handling of explosives and propellants, vehicle and payload/experiment assembly, and pad preparations where other than normal procedures are used, or operating conditions are particularly hazardous.

The Ground Safety Plan is based on information provided by the customer (See Appendix E for details), the Mission Team, and Safety personnel.

> Note: Ground Safety Data Packages are provided for operations at established ranges such as WSMR and Andoya Space.
> Ground Safety Plans are provided for operations at Wallops Flight Facility, Poker Flat Research Range, and mobile campaigns, where NASA is the lead range.

The Ground Safety Plan will typically include information on the following:

- List of all hazards associated with the mission
- Exposure limits for personnel working with hazardous material. The cardinal principle is to limit the exposure to the minimum number of personnel, minimum time, and minimum number of hazardous materials, consistent with safe and efficient operations.
- Operational restrictions to be observed by personnel during specific tests or operations
- Chemical Systems
- Cryogenic Systems
- Electro-explosive circuit requirements
- Electrical storm criteria and restrictions on safe operations
- RF restrictions on operations at specified RF levels
- Personnel requirements for safety devices, clothing, and procedures
- Radioactive sources safety requirements
- Pressure vessel safety requirements
- Security warning and control procedures
- Operational control and procedures for all areas and material related to the mission

7.4 Flight Safety Plan (FSP)

The flight safety goal of GSFC/WFF is to preclude an impact which might endanger human life, cause damage to property, or result in embarrassment to NASA or the U. S. Government. While some degree of risk exists for every mission, each flight must be carefully planned to minimize that risk while maximizing the probability of attaining mission objectives.

Prepared by the Safety Office prior to any launch operation conducted at GSFC/WFF, the Flight Safety Plan describes the quantitative and qualitative aspects of the proposed vehicle flight. For operations at other ranges, any special flight safety restrictions or requirements will be documented in the Flight Requirements Plan or other operations document.

The Flight Safety Plan is based on information provided by the mission team (See Appendix E for details) and information provided by NASA/WFF and NSROC engineering, operations, and safety personnel. Details on flight safety criteria are found in the Goddard Space Flight Center (GSFC) Wallops Flight Facility Range Safety Manual (GSFC-STD-8009) for Goddard Space Flight Center (GSFC)/Wallops Flight Facility (WFF), dated June 9, 2022. PIs are expected to determine their minimum requirements for launch based on their scientific needs/requirements. The Mission Manager will work with the Safety Office to ensure the mission requirements will meet safety criteria. The PI may be requested to participate in the planning for other safety related aspects of the mission as required.

The Flight Safety Plan will typically include information in the following areas:

7.4.1 Impact Criteria

All flights will be planned in accordance with impact agreements and conducted so that the planned impact or re-entry of any part of the launch vehicle over any landmass, sea, or airspace does not produce a casualty expectancy greater than 10^{-6}. Additionally, an impact probability on private property or off-range greater than 10^{-3} must be approved by a waiver.

7.4.2 Overflight Criteria

Vehicle overflight of a populated area may only be planned when flight termination capability exists and one or more of the following criteria are met:

- The probability of a land impact and resultant CE due to an overflight failure does not violate established criteria
- Formal government or private agreements are established which allow the overflight
- It is approved in a Risk Analysis Report and/or the Flight Safety Plan

7.4.3 Flight Termination Criteria

GSFC/WFF flight safety policy requires a flight termination system in every stage of a launch vehicle unless it is shown that the flight is inherently safe. Inherent safety is determined by probability estimates based on known system errors and qualifying conditions specified in safety regulations. Typically, unguided, spin stabilized, sounding rockets are deemed inherently safe at nominal flight elevations below 85 degrees.

If a launch vehicle cannot meet the above set of conditions, a Flight Termination System (FTS) must be employed whereby thrust may be terminated, stage ignition prevented or delayed, or other means employed to ensure that the impact and overflight criteria are not exceeded. FTS's are relatively high-cost systems and therefore missions should have a strong scientific justification if they are to be employed.

7.4.4 Flight Termination System Design Requirements

The design of a vehicle flight termination system must be submitted to the Safety Office (Code 390) for analysis and approval. The FTS design requirements are found in RCC 319 (FTS commonality standard).

7.4.5 Flight Planning Criteria

Launch vehicle flight safety is usually associated with the containment of spent stages, hardware, and payload components within planned impact areas. Since the entire set of variables (vehicle aerodynamic/ballistic capabilities, azimuth and elevation angles, wind, air, and sea traffic, and proposed impact areas) is never duplicated, each flight is unique. It is, therefore, imperative that the vehicle design, reliability, performance, and error predictions for each flight case be analyzed by the Safety Office (Code 390) to ascertain the flightworthiness of each launch vehicle.

7.4.6 Range Clearance Criteria for GSFC/WFF Launch Ranges

GSFC/WFF coordinates flight operations with the Federal Aviation Administration (FAA), the US. Navy, and other organizations, as required, to clear impact areas. The hazard areas for each rocket are defined and all flight safety criteria must be satisfied before a launch is allowed. No vehicles will be launched without prior clearance.

7.4.7 Operational Procedures

Criteria are specified for vehicles with and without flight termination provisions and include wind weighting, shipping, launch limitations, and pre-launch checks.

7.5 Safety Analysis Report

When directed by GSFC/WFF, Safety Analysis Reports are prepared to document safety risks in reference to baseline safety requirements and criteria. These reports include a summary of hard hazard analysis and state the risks that may be incurred by a sounding rocket operation. Safety Analysis Reports are also used to obtain GSFC/WFF approvals of waiver requests for exemptions from safety requirements. A typical Safety Analysis Report includes:

- Introduction and project description
- Safety criteria
- Hazard specifications, preventive measures, and risk assessment for:
- Ground safety
- Flight safety
- Environmental hazards
- Details of all safety procedures

Formal specification, justification, and risks for any waiver requested for exception from safety requirements.

Section 8: Launch Operations

Since the inception of the NASA Sounding Rocket Program in the late 1950's, the program has conducted launch activities throughout the free world. A list of sounding rocket launch sites, both past and present, is shown in Table 8-1.

Sounding rocket launch operations are currently conducted at domestic and foreign locations. Each location, and the respective facilities and support assets, vary. Some locations, such as Wallops Flight Facility and White Sands Missile Range are established ranges with dedicated facilities, personnel, and assets that support sounding rocket launch and recovery operations. Other ranges are more austere and so are equipped with temporary (or mobile) assets that are specific to a campaign. Although each range has unique requirements, some commonality exists across all ranges. This Section highlights some of the procedures common to both established and temporary ranges.

8.1 Launch Ranges

Table 8-1 identifies the locations of domestic and foreign ranges used for NASA sounding rocket launch operations. Mobile assets deployed from WFF can augment the established facilities at any range, per the campaign requirements. Details regarding the sounding rocket program support facilities, range operations, logistics, and visitor information at WFF are provided in Section 10. *Active Site*s are detailed in Appendix B.

Table 8-1: Sounding Rocket Launch Sites Worldwide

Active Sites	
Andøya Space Andøya, Norway	Fixed Range (Full Facilities)
Ronald Reagan Ballistic Missile Defense Test Site Kwajalein, Republic of the Marshall Islands	Fixed Range (Full Facilities)
Svalbard Rocket Range (SvalRak) Ny-Ålesund, Spitsbergen, Svalbard	Fixed Range (Full Facilities, Partial Assets)
Pacific Missile Range Facility Barking Sands, HI	Fixed Range (Full Facilities)
Poker Flat Research Range Fairbanks, AK	Fixed Range (Full Facilities)
Wallops Flight Facility Wallops Island, VA	Fixed Range (Full Facilities)
White Sands Missile Range Las Cruces, NM	Fixed Range (Full Facilities)
Infrequently Used Sites	
Antigua, UK	Mobile Range
Ascension Island, UK	Mobile Range
Barter Island, AK	Mobile Range
Camp Tortuguera, Puerto Rico	Mobile Range
Cape Parry, Canada	Mobile Range

Chikuni, Canada	Mobile Range
Coronie, Suriname	Mobile Range
East Arnhem, Northern Territory, Australia	Mobile Range
Eglin AFB, FL	Fixed Range (Full Facilities)
El Arenosillo, Spain	Fixed Range
Fort Churchill, Canada	Fixed Range (Decommissioned)
Fort Greely, AK	Mobile Range
Fort Sherman, Panama	Mobile Range
Fox Main, Canada	Mobile Range
Karachi, Pakistan	Fixed Range
Karikari, New Zealand	Mobile Range
Kerguelen Island, France	Mobile Range
Keweenaw, MI	Mobile Range
Kiruna (Esrange), Sweden	Fixed Range (Full Facilities)
Kourou, French Guiana	Fixed Range (Full Facilities)
Natal, Brazil	Fixed Range (Full Facilities)
Point Mugu, CA	Fixed Range (Full Facilities)
Primrose Lake, Canada	Mobile Range
Puerto Rico	Mobile Range
Punta Lobos, Peru	Mobile Range
Red Lake, Canada	Mobile Range
Resolute Bay, Canada	Mobile Range
San Marco, Kenya	Fixed Range
San Nicholas Island, CA	Fixed Range
Sardinia, Italy	Mobile Range
Siple Station, Antarctica	Mobile Range
Sondre Stromfjord, Greenland	Mobile Range
Thumba, India	Fixed Range
U.S.N S. Croatan	Shipboard (Decommissioned)
U.S.N S. Range Recoverer	Shipboard (Decommissioned)
Vandenburg Air Force Base, CA	Fixed Range (Full Facilities)
Western Test Range, CA	Fixed Range (Full Facilities)
Woomera, Australia	Fixed Range (Partial Facilities)

8.2 Launch Operations

Safety is the priority for NASA operations. Each range has unique safety considerations, and all members of the mission team must be familiar with local procedures and the governing protocols that regulate operations. Sounding rocket launch operations often occur in remote locations so medical facilities may be sparse; accidents may end personnel participation in a campaign. In addition to general safety practices, section 8.2.1 provides additional rules that should be considered during launch operations.

8.2.1 Rules to Remember

- Range Clearance: Range clearance requests must be received by the range well before the team and equipment arrive; the MM coordinates clearance requests for all mission team members. Always hand-carry a copy of the request to the range.
- Foreign Nationals: Notify the Mission Manager if a foreign national is to participate in launch operations. Requirements vary widely and change often. Notice of foreign national participation must be given months in advance. Section 10.3 outlines the information to be provided to the Mission Manager.
- Vehicle Pass: Most ranges require vehicles to display a pass to allow entry. All private and rental vehicles will be processed according to local range procedures.
- Alcoholic Beverages: Some ranges have designated eating areas where alcoholic beverages are permitted, otherwise, consumption of alcoholic beverages is forbidden.
- Photography: Some ranges have rigid restrictions on photography by other than designated personnel. It is best to discuss your photography requirements with the Mission Manager and appropriate range personnel so arrangements can be made.

8.2.2 Role of the Mission Manager

Timely field operations require teams to act in parallel and personnel must be flexible facilitate a safe and successful launch or launches. For example, the range team may be focused on ground-based telemetry assets and weather tracking, while the payload team is validating sub-system function and the science team is preparing instrumentation for flight. Change in status is constant so effective communication is necessary, especially with the Mission Manager. The Mission Manager is the primary point of contact during launch operations. Questions about schedules, range boundaries and buffer zones, flight termination, and transportation should be fielded through the MM The location of everyone participating in the launch should be always known to him/her. The MM should be constantly apprised of changes, delays and problems encountered. The Mission Manager will confirm that unresolved issues are addressed, procedures strictly adhered to, and the overall success of the mission is ensured.

8.2.3 The Flight Requirements Plan

The NSROC MM prepares the Flight Requirements Plan (FRP) or operations directive (discussed in Section 2). The plan is sent to the range several weeks before the team arrives at the range. The FRP includes data on the rocket and the experiment and lists all the supporting activities that the range must provide for launch and recovery operations. The range coordinates its functions based on the FRP. For operations at mobile ranges, the Campaign Manager includes the same information in the Operations Document.

8.2.4 Test and Evaluation

Most launch ranges do not have test and evaluation facilities. Therefore, T&E will be complete prior to shipment of the experiment and support equipment to the range. T&E is typically conducted at WFF, or at WSMR.

8.2.5 The Field Schedule

Prepared by the Mission Manager, the field schedule lists every major operation. Any change needed to the Field Schedule should be made known to the Mission Manager as soon as possible.

8.2.6 The Preflight Conference

Shortly after arrival at some range sites, the PI and designated WFF personnel will meet with range personnel for a Preflight Conference. Attendees review the mission requirements, thoroughly discuss all aspects of range support operations, and coordinate those operations with the PI's activities. Any anticipated problems are resolved or become action items.

8.2.7 Recovery

Payload recovery requires extensive planning. In the event of a failure, the recovered rocket (inclusive to the vehicle, payload, or parts therein) are considered property of NASA until an inspection has been completed per the Mission Manager.

8.2.8 Post-Flight Conference

Typically, before leaving the field, a Post-Flight Conference is held to present any compliments or complaints regarding field services to range and WFF personnel. Suggestions for improved operations may also be presented at this time. Based on the information on hand, brief reports on the success of the mission are presented and any known anomalies are reviewed.

8.3 Foreign Ranges

Foreign ranges have additional responsibilities and procedures for the PI. While the scientific and technical procedures are like those employed by domestic ranges, the use of foreign ranges requires additional considerations such as shipping, personnel travel, communications, and lodging. The SRPO coordinates foreign range support and special provisions. Appendix B discussed launch ranges in more detail, including the types of facilities and assets available. Figure 8.3-1 shows the range at Andoya Space, Norway - a fixed range with full facilities.

Figure 8.1: Range Facilities at Andøya Space

8.3.1 Experimental Techniques

Some experimental techniques such as chemical releases, onboard radioactive sources, or explosive payloads; require additional coordination with the U.S. Department of State and foreign governments. Adequate time must be built into the schedule to allow for obtaining the necessary authorizations.

8.3.2 Travel & Lodging

The Mission Manager can supply current information on available lodging and travel, including rates and distance from the site. PIs are responsible for their team's travel and lodging arrangements.

8.3.3 Access

Access to foreign ranges is controlled by the foreign government or other designated institutions; their requirements must be adhered to. The Mission Manager can advise on proper procedures. Passports and visas are mandatory when visiting foreign ranges. Passports expiring within one month of reentry into the United States are discouraged. Personnel should renew their passports if this is the case.

8.3.4 Foreign Nationals

The host country controls access to foreign ranges for foreign nationals. Recall from Section 2, a TAA is required for NSROC personnel to interface with foreign nationals.

8.3.5 Shipping and Export Control

The Mission Manager works closely with NASA shipping and export control personnel to ensure all payload hardware and GSE arrives at the range in a timely manner. Since NASA must obtain an export license for the shipment, planning must begin much earlier than for launches from domestic ranges. Generally, for missions launched at foreign ranges, all experiment hardware and GSE is shipped to WFF then consolidated into one foreign shipment that is covered by a NASA export license.

A new method employed in recent years, known as "Ship and Shoot", is streamlining field operations thus reducing the amount of time teams are deployed in the field. To effectively implement ship and shoot, the payload is fully assembled at WFF and shipped to the field in a controlled and measured environment. The number of payload operations needed in the field is thus minimized. This method has been used at both foreign and domestic ranges successfully, especially for payloads that have smaller form factors. Ship and Shoot requires additional planning up-front, and it should be discussed with the Mission Manager if desired.

8.3.6 Postal Service

Postal services are available at active launch sites. The Mission Manager can provide the postal address of the foreign range. Internet access is available at all active launch sites at varying speeds.

8.4 Mobile Range Operations

Mobile range operations are conducted worldwide in locations dictated by scientific requirements. WFF owns and operates the mobile support systems necessary to conduct sounding rocket campaigns worldwide.

The selection and use of a mobile range entail a high degree of planning, coordination, and cooperation. Figure 8.4-1 shows an operation at the mobile range at Kangerlussuaq, Greenland. This range and the range at Arnhem Space Center, Australia (Figure 8.4-2), exemplify the adaptability of mobile operations in extreme conditions. While precipitation at each range is similar, the temperatures are different - the Australian range is a hot and humid, while the Greenland range experiences arctic conditions. Despite the differences, many requirements are similar. For example, environmental protective covers and other similar ground support equipment is required in both locations, and similar rockets are flown.

Figure 8.2: Range Support Operations in Kangerlussuaq, Greenland

Figure 8.4-2 shows the Arnhem Space Center, Australia range build-up during the Astrophysics campaign in 2022.

Figure 8.3: Arnhem Space Center, Australia

Mobile ranges generally have common characteristics that provide challenges to the efficient and effective planning required to conduct sounding rocket campaigns. Some of the more challenging conditions are:

8.4.1 Remote Locations

Mobile ranges are frequently located in remote locations with limited habitability and sparse land, sea, and air communications. Transportation to and from the range, including customs clearance for equipment and personnel, is a major planning consideration. Living conditions can be inconvenient and the availability of lodging can limit team sizes. Medical facilities may not be readily available.

8.4.2 Harsh Environment

Some mobile ranges are in harsh environments which is an additional challenge to the proper functioning of equipment. Consideration of range environmental conditions should be discussed throughout the mission lifecycle.

8.4.3 Limited Technical Facilities

Because remote ranges frequently have limited technical facilities (such as communication systems, launchers, ground support equipment, and shelters, to name a few examples) these must be provided. Campaign work trips often take place months prior to the mission team's deployment to establish the range and overall, limit the campaign length. Payloads must be fully tested prior to deployment to remote ranges.

8.4.4 Limited Communications

Communication may be limited at the range and between the range and remote sites. For example, prior campaigns in Kwajalein have required remote camera sites on barrier islands necessitating the use of satellite phones for communication. To meet communication requirements, teams may temporarily install equipment and run cable/fiber to establish communications with personnel or with the rocket. Some ranges, especially established ranges, have RF limitations preventing the use of short-range radio communications. These considerations need to be addressed prior to deployment so launch operations are not inhibited.

Section 9: Data Processing and Analysis

WFF data processing and analysis facilities and systems provide a wide range of support for sounding rocket testing and operations by means of data acquisition and analysis. This Section describes those systems and procedures by which PIs can obtain the support required for the experiment.

9.1 Computer Systems

General purpose computer support is provided by GOULD/SEL Concept/32 minicomputers organized into a Data Processing Installation (DPI). The three DPI systems most directly involved in sounding rocket projects are the Real-Time Computer System, Data Reduction Computer System, and the Engineering Computer System.

9.1.1 Real-Time Computer System (RTCS &RTBS)

Used primarily as a range safety tool, the RTCS & RTBS are two systems in a network of tracking radars and communications-supporting control and data display facilities in the Range Control Center. The single point, failure-tolerant system accurately predicts the impact point of any vehicle launched from WFF and can transmit separate command functions to the vehicle. These commands vary from vehicle stage initiation to actuating command devices onboard the payload. If payload recovery is required, the RTBS & RTCS provides a recovery location.

Figure 9.1: Wallops Flight Facility Control Center

Sounding rockets launched from WFF are unguided. Low level winds can alter the trajectory of the rocket, so the nominal launch azimuth and elevation of the rocket is adjusted during the hot count to compensate for these winds. To aid range safety personnel in determining the compensation required, wind weighting is performed by the redundant Wind Weighting computers in the Range Control Center. Wind profile data is collected from meteorological system sensors, chaff, and radio sondes from ground level to an altitude of 129,000 feet. In addition to providing range safety information, the Wind Weighting Computers can provide look angles (slave angles in elevation and azimuth that enable the radar or telemetry antenna to acquire the target) to any radar or telemetry installations which have compatible formats.

9.1.2 Data Reduction Computer System (DRCS)

The primary application of the DRCS is to perform flight radar data reduction operations. Data from other positional sources such as optics, telemetry, and special sensors can be incorporated. The DRCS also processes some telemetry data such as attitude data reduction from onboard gyros, such as the Space Vector Corporation MIDAS platform.

9.1.3 Engineering Computer System (ECS)

The ECS directly supports sounding rocket missions. ECS analytical tools and capabilities include the following:

- Launch Vehicle Physical Properties
- Aerodynamic Characteristics Determination
    - Subsonic, Supersonic, Hypersonic
    - Linear, Non-linear
    - Launch Vehicles, Re-entry Bodies.
- Flight Simulation (Endo-Exo atmospheric)
    - Launch Vehicle Performance (Flight Trajectory)
    - Launch Vehicle Stability (Static, Dynamic)
    - Launch Vehicle Guidance
    - Payload Dynamics, Attitude Control
    - Special Studies (Magnetic Field, Solar Eclipse Geometries)
- Flight Loads & Structural Analysis
    - Launch Vehicle Vibrational Modes
    - Aeroelastic Effects
    - Vehicle/Payload Mechanical Design
- Thermal Analyses (1,2, & 3-D Nodal Networks)
    - Aero heating (Ascent and Re-entry)
    - Spacecraft Thermal Studies
    - Shuttle Bay Payload Thermal Analysis

9.1.4 Launch Status Review System (LSRS)

The LSRS, in association with the ECS, provides a capability for monitoring launch conditions during operations at White Sands Missile Range. Wind profile data, launcher settings, and simulated trajectories are transmitted to WFF in real time and captured in IBM PC/AT computers. Selected data are then sent to the ECS for display. Wind profile data may be used as input to various flight simulations for guided vehicles; the output is then used to assess control system behavior and vehicle flight characteristics.

9.1.5 Special Purpose Computers

Many special purpose microcomputer and minicomputer installations support sounding rocket experiments and operations. The MM can advise which ones may be the most helpful in correlation with the experiment.

9.1.6 Digital Telemetry Facility

The Digital Telemetry Facility is linked by cable to the telemetry receiving stations and readout stations. This Facility:

- Conditions, synchronizes, and processes vehicle and payload performance serial PCM data
- Digitizes and processes analog FM data
- Formats digital tapes
- Displays selected data or parameters in binary, decimal and engineering units
- Prints data in selected formats or provide data tapes for further reduction by the processing lab or the PI.

9.2 Obtaining Data Processing and Analysis Support

Arrangements for data processing and analysis support should be incorporated into pre-mission planning and coordinated with the MM.

9.2.1 Flight Requirements Plan (FRP)

Basic data processing and analysis requirements are provided by the PI in the FRP which was described in Section 2. The FRP provides the processing lab with the background information needed prior to processing the data. It should describe the test and the expected results to be obtained. The test schedules and data requirements must be defined in advance to assist in planning the workload and manpower requirements. The PI submits the data requirements for the FRP to the MM. Basic information needed for the FRP includes:

- Project identification including the job order number
- Priorities, deadlines, and deliveries
- Special processing needs (such as refraction calibration)
- Location and time of the experiment
- Objectives of the experiment
- General processing requirements (raw versus smoothed data, reference coordinates)
- Data dissemination requirements (hard copy reports, graphics, magnetic tape)

The data sampling requirements, which consist of timing intervals of the raw data as it is collected and the intervals to be processed, must be clearly spelled out. Other pertinent information may be needed depending upon the data requirements.

9.2.2 Instrumentation (Telemetry)

Real-time and post-flight data is normally requested through the Telemetry Engineer. Real-time requirements for displays and paper charts are submitted to the Telemetry Engineer who, in turn, prepares the necessary ground station support request. Basic RF link and airborne telemetry specifications are provided in the FRP. The ground station support request forms vary with each launch site and are revised and submitted to the facility supervisor prior to the final launch countdown.

Actual flight events, established after quick-look review of real time data, frequently require changes to the post-flight data playback needs of the Mission Team. These changes are submitted, via the Telemetry Engineer, to the ground station personnel. Playback operations are observed to evaluate completeness and accuracy of the data.

9.2.3 Non-Standard User Requirements

Should the PI require a technical capability not currently available at WFF, he/she can either provide WFF with the computer programs, or WFF can develop the capability. If WFF is to develop the capability, the PI should contact the SRDM and outline the requirements.

9.2.4 Positional Data Policy

To standardize the earth model between impact prediction and data reduction, the WGS84 Ellipsoid/North American Datum of 1983, is used for data products generated by the WFF Data Processing Installation. Wallops Internal Publication WFF-822.95-001, Geodetic Coordinates Manual for NASA Goddard Space Flight Center, Wallops Flight Facility, January 1995, contains coordinate information on WFF and other sounding rocket and balloon facilities.

9.2.5 Data Dissemination

All data are disseminated through the Mission Manager. The data package produced for sounding rocket missions includes all tracking and telemetry data supporting the mission and processed to meet the requirements of the PI. Telemetry reports are shared via box (https://nasagov.app.box.com)in the format shown in Appendix D.

Prior to dissemination, all material will complete a quality control review to determine that all data is of satisfactory quality and the request has been fulfilled.

9.2.6 Data Retention

Analog and/or Digital telemetry flight data tapes are retained for five years. Telemetry data is currently digitized and stored on servers in PTP format and will be retained by the NSROC EE group for five years. For positional data, original data paper records are retained for one year and all unedited/unsmoothed data measurements are retained for a period of four years. Processed positional data is retained indefinitely.

Section 10: Wallops Flight Facility

Wallops Flight Facility is located on the Delmarva Peninsula approximately 80 miles northwest of Norfolk, VA and 40 miles southeast of Salisbury, MD. WFF sprawls over some 6,000 acres of prime property on Virginia's scenic Eastern Shore. U.S. Route 13 runs the entire length of the Peninsula and connects with major routes along the Atlantic Coastline from Maine to Florida. WFF is linked with the Norfolk-Hampton Roads area by the Chesapeake Bay Bridge Tunnel and to Washington DC and Baltimore, MD by the Chesapeake Bay Bridge.

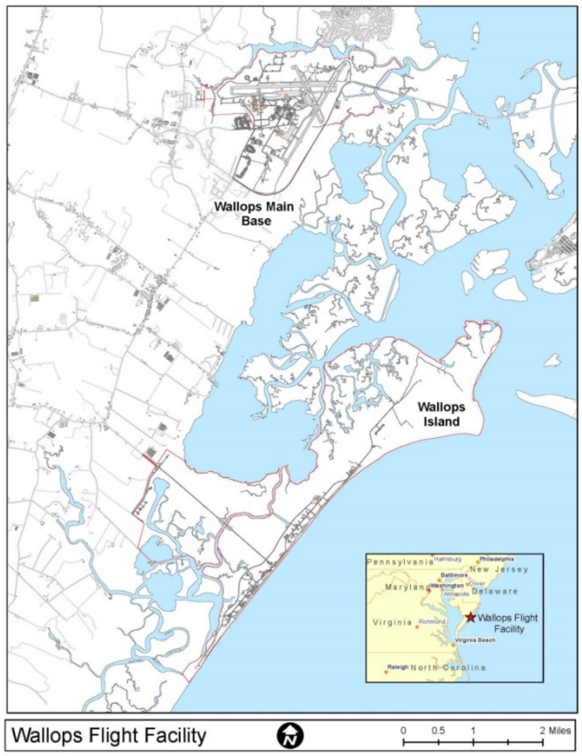


Figure 10.1: Wallops Flight Facility Map

WFF consists of three separate properties: the main base, Wallops Island launch area, and the Wallops mainland.

The Main Base (Figure 10-2) houses the management and engineering offices supporting NASA's sounding rocket, balloon, and aircraft projects. Facilities includes administrative offices, technical service support shops, rocket inspection and storage areas, an experimental research airport, laboratories, the main telemetry building, the Range Control Center, a large computer complex, and telemetry, radar, and communication facilities. The Dobson Total Ozone Measurement Facility and the Ionosonde transmitters are also located here. The National Oceanographic and Atmospheric Agency, the U.S. Navy, the U.S. Coast Guard, and the Mid-Atlantic Regional Spaceport have tenant activities located here. Several contractor facilities are located in close proximity to the main base but are not involved in sounding rocket activities.

Figure 10.2: Wallops Main Base

The Wallops Island Launch Site, named after 17th Century surveyor John Wallop, is a barrier island (six miles long and one-half mile at its widest point). Wallops Island is located approximately seven miles southeast of the main base. A causeway and bridge connect the Wallops Island mainland with the Wallops Island launch area across two miles of march and intercoastal waterway. The Wallops Island launch area supports a multitude of programs including NASA Sounding Rockets, NAVY AEGIS, Northrop Grumman, Rocket Labs, and DOD partners, to name a few. Sounding rockets utilize the launch sites (launchers and surrounding areas), blockhouses, assembly shops, dynamic balancing facilities, and motor storage. Wallops Island launch area is also home to the NSROC Launcher Systems Group (Building W-40). Figure 10-3 is a photo of Wallops Island looking north.

Figure 10.3: Wallops Island

Wallops Mainland, a half-mile strip of land at the opposite end of the causeway behind the Island, is the location for the long-range radars, command destruct transmitters, and communications transmitter facilities. Figure 10-4 is a photo of the Wallops Mainland.

Figure 10.4: Wallops Mainland

Geographically, WFF is located at 37.8° N 75.5° W.

10.1 WFF Sounding Rocket Program Support Facilities

The primary support functions for the NASA Sounding Rocket Program include sounding rocket design, fabrication, integration, environmental testing, launch, recovery, and data acquisition and analysis; all of which have been thoroughly discussed in previous sections of this handbook. The facilities which support these functions are used by scientists and engineers from NASA research centers, foreign and U. S. Government agencies, universities, and the worldwide scientific community.

10.1.1 Engineering Support Facilities

Highly skilled teams of engineers and technicians work in dedicated facilities to support the implementation of the program. Such activities include the following: mission feasibility, analysis and design studies, payload engineering (mechanical, electrical, and guidance), vehicle system engineering, integration, testing, and data acquisition/analysis.

10.1.2 Payload Integration Laboratory

The Payload Integration Laboratory includes facilities for payload integration and assembly (mechanical and electrical) and for payload checkouts. The laboratory is capable of processing multiple payloads simultaneously. Telemetry ground stations are operable throughout the facility and clean room facilities are in an adjacent building. The telemetry ground station can support simultaneous links for monitoring and data recording and playbacks Figure 10.1.2-1 shows a plasma physics payload undergoing integration in the Payload Integration Laboratory at WFF.

Figure 10.5: 36.361 UE During Payload Integration at WFF

10.1.3 Environmental Testing Laboratory

Environmental testing of assembled payloads, sub-assemblies and components is accomplished at the WFF Environmental Testing Laboratory. By exposing sounding rocket systems to enveloped flight environments, the robustness and function of the payload is verified. The laboratory is adjacent to the Payload Integration Laboratory for convenience in payload handling and logistics. A detailed discussion of environmental testing policies and test equipment is included in Section 6.

10.1.4 Payload Fabrication

The WFF Mechanical and Electrical Fabrication Facilities are capable of fabricating sounding rocket payloads and launch vehicle components, including electrical components such as circuit boards, cables, and custom interfaces between experiment components.

Figure 10.6: F-10 Machine Shop

Figure 10.7: F-10 Electrical Fabrication

10.1.5 Computer Support

Special purpose and general-purpose computer systems at WFF perform preflight and flight mission analysis, data reduction, vehicle and payload analysis and support flight operations. Section 9: Data Processing and Analysis explains the available capabilities in more detail and outlines how PIs obtain support.

10.1.6 Range Operations

WFF has a comprehensive complement of operational facilities providing a broad range of support for sounding rocket, balloon, and aircraft operations. These include the following:

- Meteorological Facilities: Wind data systems support launch operations. Fixed, balloon borne, and optical sensors are available for coordinating experimental data with existing conditions. WFF is supported by NOAA data systems and a local forecasting office. The Ionospheric Sounding Rocket Station provides detailed data on ionospheric characteristics; the Dobson on the Wallops Mainland provides total ozone measurements, and a lightning detection system tracks lightning conditions over a wide area of the eastern United States.
- Ground Tracking Facilities: Several mobile and fixed radars and related data facilities support sounding rocket missions. The radars operate in the S, C, and X-bands. Tracking radars operate in C, the debris radars from Kennedy operate in X, and the surveillance radar operates in S-band.

Figure 10.8: WFF Fixed Radar System

- Telemetry Facilities support real time telemetry acquisition and data reduction and provide data for detailed analysis.
- Launch Facilities are located on Wallops Island. Facilities include pad, launcher, checkout, fire control and communications systems. Facilities can support all NASA sounding rockets. The range extends easterly over the Atlantic Ocean.
- A variety of Payload Recovery Facilities are available. Water recovery operations are coordinated through either the local U.S. Coast Guard in Chincoteague, Virginia, or via a contract between NASA and local commercial entities. Positioning systems, which included in the payload package, assist recovery.
- Aircraft and Airfield Support is available by contacting the WFF Range & Mission Management Office (Code 840). This includes surveillance, transportation, optical and visual data acquisition, and telemetry support. There are three runways ranging in length from 4,800 to 8,750 feet. Control Tower support is available. Procedures for use of the airfield are contained in HDBK-000001, 36FC1, Rev B, Wallops Airfield Operations Manual). Would this manual be hyperlinked?

- An extensive network of Command, Control, and Communications Facilities support launch operations. Several facilities support specific aspects of the operation such as radar plots and quick-look data acquisition. The focal point, however, is the Range Control Center on the Main Base which controls launches, range safety, command/destruct functions, timing, and mission countdowns through instantaneous communications with all involved activities. Quick look data acquisition, graphic displays, and video views of launches are available.
- Mobile Range Facility and Rocket Launching. Mobile range instrumentation vans support payload, meteorological, radar, control, telemetry, communications, power, and data functions. These facilities serve as mobile launching and tracking stations which can be set up as land-based stations throughout the world or on board a large ship, such as a barge, for experiments in international waters. All instrumentation vans are environmentally controlled and are provided with communications, local intercom, precision timing, and data displays. Vehicle and payload handling and storage facilities are available. Several launchers, variable in both elevation and azimuth, which can safely handle multi-stage vehicles are also available.

10.2 Working at Wallops – Rules, Regulations, and Logistics

The normal WFF workday is 0800 to 1630, Monday through Friday. However, employees generally have flexible work schedules which extend as early as 0600 and as late as 1800, typically work at other times must be coordinated with the Mission Manager to ensure access to required facilities and the availability of necessary technical personnel. All U.S. Government holidays are observed.

10.2.1 Access

Access to the Main Base and the Island/Mainland complex is controlled by guarded gates. PIs should provide the Mission Manager with identification, dates of visit, and confirmation of citizenship prior to arrival so that the necessary access badges can be obtained. The Main Base Badging Office is a necessary first stop for any WFF visit and is located just outside the main gate.

10.2.2 Accommodations

Housing, cafeteria, and recreational facilities, as well as internet, telephone, mail, and services are available at WFF:

- Housing: Two dormitories on the Main Base provide accommodations for NASA and other personnel on temporary duty at WFF. Use must be coordinated through the Mission Manager. Many visitors prefer to use local motels and restaurants, available year-round on neighboring Chincoteague Island.
- The Main Base Cafeteria is in Building E-2. Breakfast (0700 to 0900) and lunch (1100 to 1300) are served. The Williamsburg Room may be reserved for special events including group evening meals.
- Mail and Delivery Services: The WFF Post Office is located on Anderson Road, behind the cafeteria and adjacent to the e-series administrative buildings. Express Delivery Services are provided by United Parcel Service (UPS) and Federal Express daily.
- Transportation: Once clearance is approved through the Main Base Security Office, personal transportation is generally used on the Base. Transportation of sounding rocket components

by truck is arranged by the Mission Manager. Packing, shipping/receiving and material handling of equipment and components is detailed in Section 10.2.4 below.

- Telephone: Federal Telecommunications System (FTS) service is available to U. S. Government users for official calls only. External calls may be placed by dialing “9”.
- Airport: Chartered and private aircraft, both propeller and jet types, may land for business purposes at the WFF Airport, with prior approval clearance. The nearest commercial airports are in Salisbury, Maryland, (40 miles north) and Norfolk, Virginia, (70 Miles south). Rental cars are available at both locations.
- Medical: In addition to the WFF clinic for medical and emergency rescue capabilities, WFF maintains communications with local emergency rescue and medical organizations. Major medical and hospital facilities in the surrounding Virginia and Maryland counties include Riverside Shore Memorial Hospital in Onancock, Virginia, and Peninsula Regional Medical Center in Salisbury, Maryland. Emergency rescue and ambulance support is available from surrounding communities.
- Police: WFF maintains a federally trained and certified security police force that provides access control, law enforcement, response to calls for service and security for various operations both on the Main Base and on Wallops Island. They are armed and equipped with patrol vehicles and off-road vehicles that allow for total all weather access at both sites. A public safety dispatch center provides a 911 emergency answering point and dispatch for WFF Police, Fire and EMS operations. WFF dispatch maintains communications with local police, fire, and EMS services. Law Enforcement mutual aid as well as police services outside the confines of the WFF is provided by the Accomack County Sheriff’s Office and the Virginia State Police.
- Fire Protection: WFF maintains its own Fire Department. Additional support is provided by volunteer fire companies located in Accomack County. They are equipped with modern fire trucks, firefighting equipment, ambulances, and state certified volunteer staffs to provide emergency first aid, and rescue and firefighting services. There are fire houses on both the Main Base and on Wallops Island.
- The NASA/WFF Gift Shop is in Building E-2, adjacent to the cafeteria.
- The NASA Visitors Center and Gift Shop is located on Route 175 about one mile from the WFF Main Base Gate. The Visitors Center includes a collection of spacecraft and flight articles as well as exhibits about America’s Space Flight Program. Video presentations can be viewed and special events such as model rocket launches are scheduled weekly. No admission is charged. Smoking is prohibited in all GSFC buildings and around building main entrances. Designated outdoor smoking areas are available.

10.2.3 WFF – Safety Rules and Regulations

Safety restrictions and industrial safety procedures are strictly enforced at WFF. Safety requirements for sounding rocket operations are discussed in detail in Section 8 of this Manual; the WFF Safety Manual is available on request or can be downloaded from the WFF website at http://www.wff.nasa.gov. Safety questions should be directed to the Mission Manager or specific facility personnel. The NSROC Safety and Mission Assurance group will advise on proper procedures for such things as safety shoes, hard hats, gloves, safety glasses, static dissipative clothing, and masks.

PI equipment is the responsibility of the PI and their support staff. Use of this equipment needs to be coordinated with the Mission Manager, so it does not interfere with other activities, especially if the equipment radiates. Radiating equipment may be hazardous to personnel and or could interfere with other tests or day-to-day activities at WFF. Likewise, PIs and their support staff must observe and regard control signals, especially around high-energy antennas, or other radiating equipment. In addition, if PI equipment needs to operate overnight, this should be communicated to the Mission Manager. This also applies to equipment that should not be disturbed (turned on/off, moved, or adjusted).

10.2.4 Shipping/Receiving and Transportation of Sounding Rocket Components

The following address should be used for shipment to WFF; be sure to include the name and code number provided by the MM in Freight Destination Address.

Mailing Address:
Full Name, NASA Code
NASA
Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, Virginia 23337

Freight Destination Address:
Full Name, NASA Code
NASA
Goddard Space Flight Center
Wallops Flight Facility
ATTN: Receiving, Building F-l9
Wallops Island, VA 23337

Delivery services generally include:

- Motor Freight Truck Services: All cargo and freight are received at Building F-l9, except Class "A" and "B" explosives, and certain other hazardous material requiring advance notice of shipments. Inbound shipments of Class "A" and "B" explosives, and other designated hazardous materials will stop and park at the WFF Main Gate. Any shipment requiring the delivering carrier's equipment to fly placards, and all shipments tendered as truckload, require RESHIP information in advance of delivery. Normal receiving hours: 0800 to 1430 (for truckloads) and 0800 to 1600 (for partial loads), Monday through Friday, excluding holidays.
- Air Freight Services to and from WFF is provided by Federal Express, Emery Worldwide, Bax Global, T.F. Boyle, Roadway Express and Roberts Express.
- Packing: The PI is responsible for packing and unpacking the experiment and associated equipment. The Mission Manager can furnish additional information on packing criteria upon request. Alcohol, explosives, corrosives, flammables, and radioactive sources must be packaged separately. Radioactive sources require prior approval from the WFF Safety Office. Batteries must be packaged separately from electrolytes. Squibs are normally sent in separate containers. If squibs are included in a payload, the payload container must be marked to indicate squibs, and sent as a hazardous shipment.
- Material Handling Equipment: Forklifts, overhead hoists, and dollies are available for use at WFF. All material handling equipment must be operated by WFF personnel; however, special training can be arranged to allow customer operation of GSE. Any special equipment must be furnished by the PI.
- Customs: Any international shipment should be routed through the Port of Baltimore. Notify your Mission Manager prior to shipment for coordination with US Customs clearance authorities.

10.3 Foreign Nationals

Foreign nationals who need to visit WFF or other launch facilities - particularly White Sands Missile Range - must provide information to the Mission Manager regarding their visit(s). Requirements change often so the Mission Manager must be notified as soon as possible; preferably at the MIC. PIs should be aware that it often takes 3 months or more to get the proper paperwork in place.

Appendix A: Sounding Rocket Launch Vehicles

A.1 Black Brant Launch Vehicle (21.XYZ)

General

The Black Brant is a single stage, solid propellant, sounding rocket developed by Magellan Aerospace in Winnipeg, Canada. There is a 3-fin and a 4-fin version. Figure A.1-1 shows the Black Brant launch vehicle.

Figure A.1: Black Brant Launch Vehicle

Vehicle Performance

The single stage Black Brant rocket motor produces an average thrust of 20,260 pounds and an action time of 27.5 seconds. The primary diameter of the Black Brant is 17.26 inches, and it is 208 inches long with the standard exit cone. Loaded weight of the motor, including hardware, is 2,785 pounds which includes 2,223 pounds of propellant.

Payload

The standard payload configuration for the Black Brant vehicle is 17.26 inches in diameter with a 3:1 ogive nose cone. Payload length and weight is typically limited to approximately 260 inches and 1,400 pounds. Because of the dynamic pressures, bulbous payloads larger than 17.26 inches in diameter cannot be accommodated on the single stage Black Brant vehicle. Standard sounding rocket subsystems are compatible with the Black Brant motor which provide flexibility to meet experiment requirements. These modular systems include attitude control systems, guidance systems, recovery systems, separation systems, and de-spin systems.

Performance Graph

Performance capabilities for the single stage Black Brant vehicle are shown in Figure A.1-2.

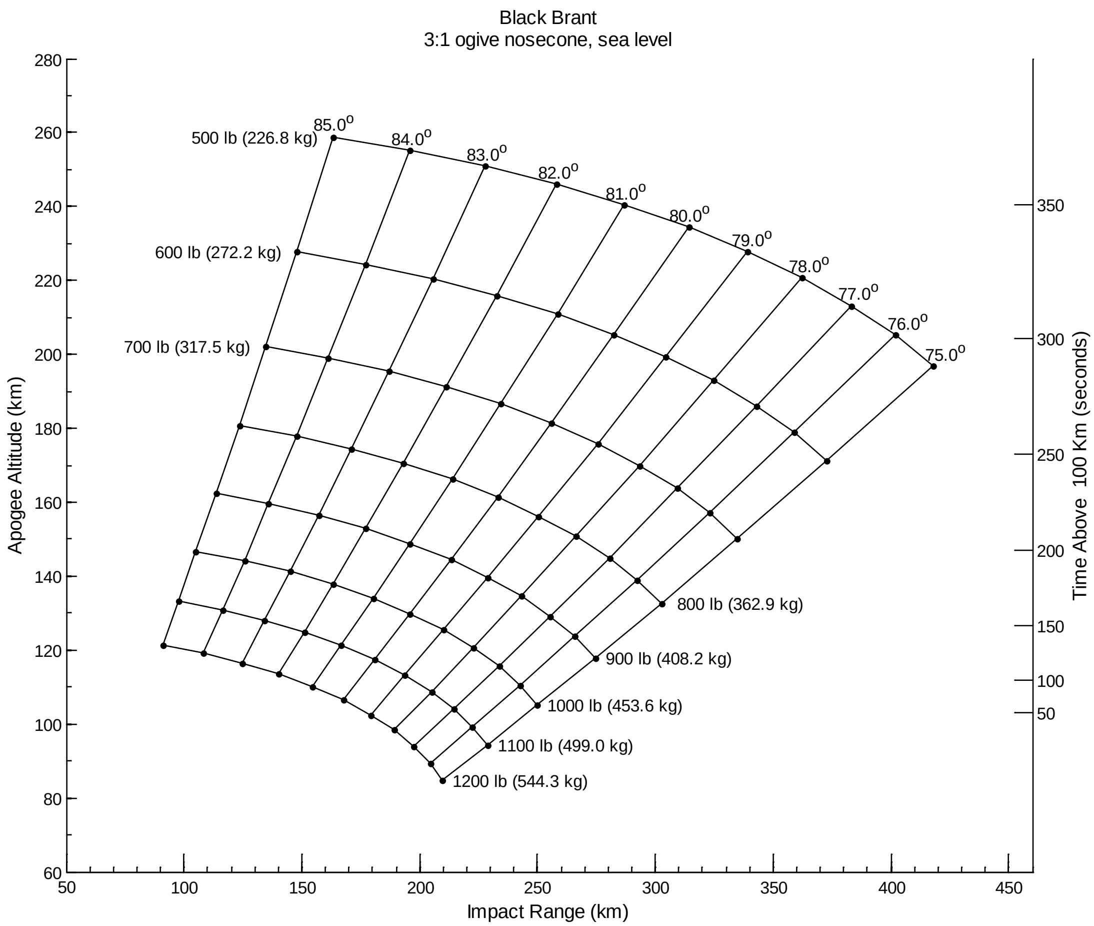


Figure A.2: Black Brant Launch Vehicle Performance

A.2 Improved Orion Launch Vehicle (30.XYZ)

General

The Improved Orion motor is an unguided and spin stabilized, surplus military rocket motor with a dual phase propellant system that produces thrust levels of approximately 20,000 pounds for the first 6 seconds and approximately 4,000 pounds until burnout at 24 seconds. There is a 3-fin and a 4-fin version. The fins are canted to generate a vehicle spin for in flight stability and impact dispersion. Figure A.2-1 shows the Improved Orion launch vehicle.

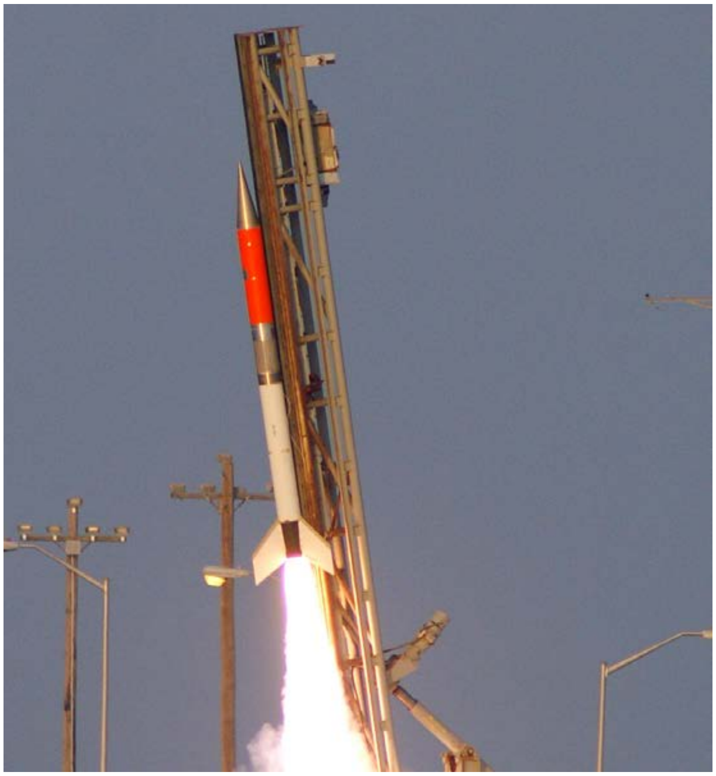


Figure A.3: Improved Orion Launch Vehicle

Vehicle Performance

The Improved Orion is 14 inches in diameter, 105 inches long, and 943 pounds. The rocket has the capability to carry a 100-pound payload to 110 kilometers and a 200-pound payload to 80 kilometers when launched from sea level at an 85-degree launch elevation, see Figure A.2-2.

Payload

The typical payload for the Improved Orion has a principal diameter of 14 inches and can utilize several nose cone shapes. The typical payload length varies from 75 to 140 inches, though this is not the maximum envelope. Standard 14-inch diameter hardware systems, such as nose cones, separation systems, recovery systems, and de-spin systems, are compatible with the Improved Orion vehicle.

Performance Graph

Performance capabilities for the single stage Improved Orion vehicle are shown in Figure A.2-2.

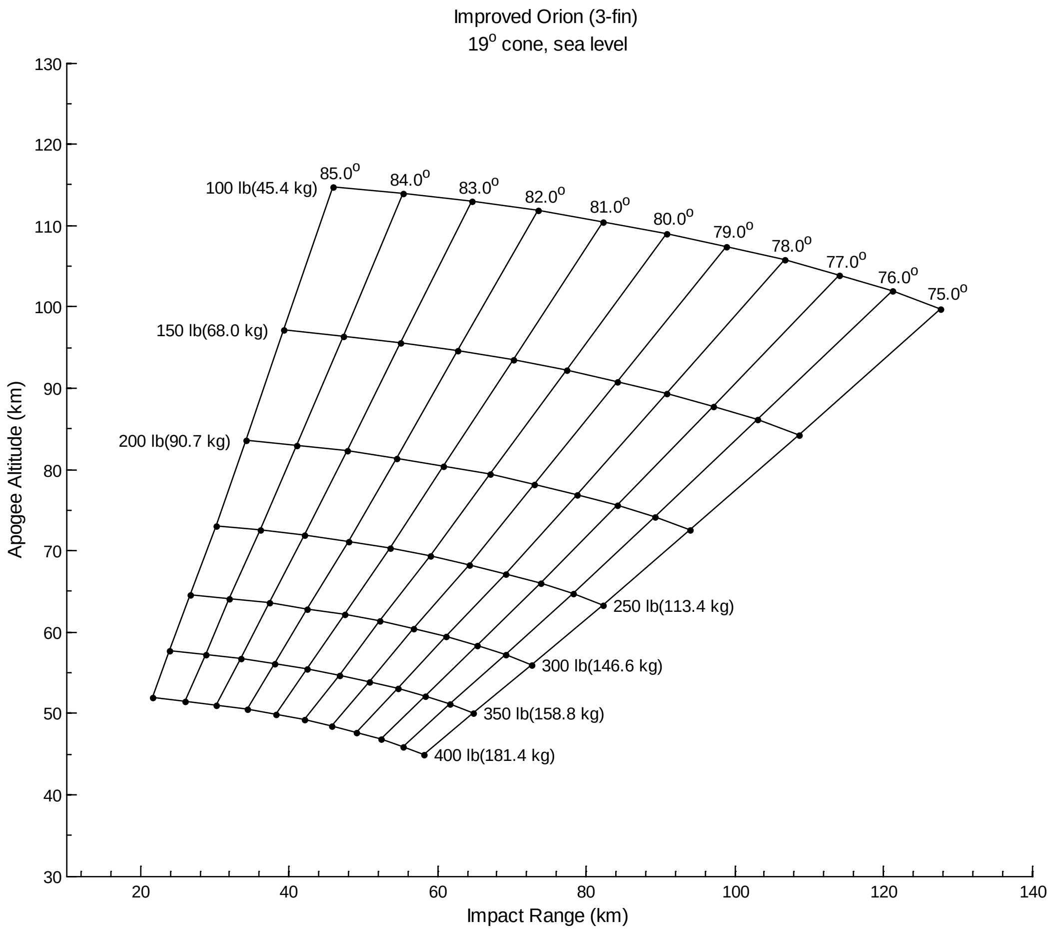


Figure A.4: Improved Orion Launch Vehicle Performance

A.3 Black Brant X Launch Vehicle (35.XYZ)

General

The Black Brant X launch vehicle has three stages. The first stage is a military surplus, Terrier motor, second stage is the Black Brant motor, and the final stage is the Nihka motor. The Nihka is ignited once the vehicle is exo-atmospheric and is thus, fin-less. Figure A.3-1 shows the Black Brant X launch vehicle.

Figure A.5: Black Brant X Launch Vehicle

Vehicle Performance

The first stage booster is a Terrier rocket motor with four, $2.5\,ft^2$ fins arranged in a cruciform configuration. The Terrier booster is 18 inches in diameter and 169 inches long. The Black Brant rocket motor with the extended exit cone produces an average thrust level of 23,317 pounds with an action time of 27.5 seconds. The primary diameter of the Black Brant is 17.26 inches and is 223 inches long. The loaded motor weight, including hardware, is 2,827 pounds which includes 2,223 pounds of propellant. The third stage, Nihka motor, was developed by Magellan Aerospace specifically for exo-atmospheric conditions. The average thrust is 9,551 pounds with a total impulse of 193,754 pound-seconds. The diameter is 17.26 inches and the loaded motor weighs 906 pounds with 696 pounds being propellant.

Payload

The standard payload configuration for the Black Brant X vehicle is 17.26 inches in diameter with a 3:1 ogive nose cone. Payload length and weight limits are not as well defined as most Black Brant vehicles. Payload acceptability is evaluated per mission. Flown payloads have reached 800 pounds and 225 inches long. The nose cone can be removed before Nihka burn to increase overall performance of the launch vehicle.

Standard sounding rocket subsystems are compatible with the Black Brant X motor stack which provides flexibility to meet experiment requirements. These modular systems include all attitude control systems, recovery systems, separation systems, and de-spin systems.

Performance Graph

Performance capabilities for the Black Brant X vehicle are shown in Figure A.3-2.

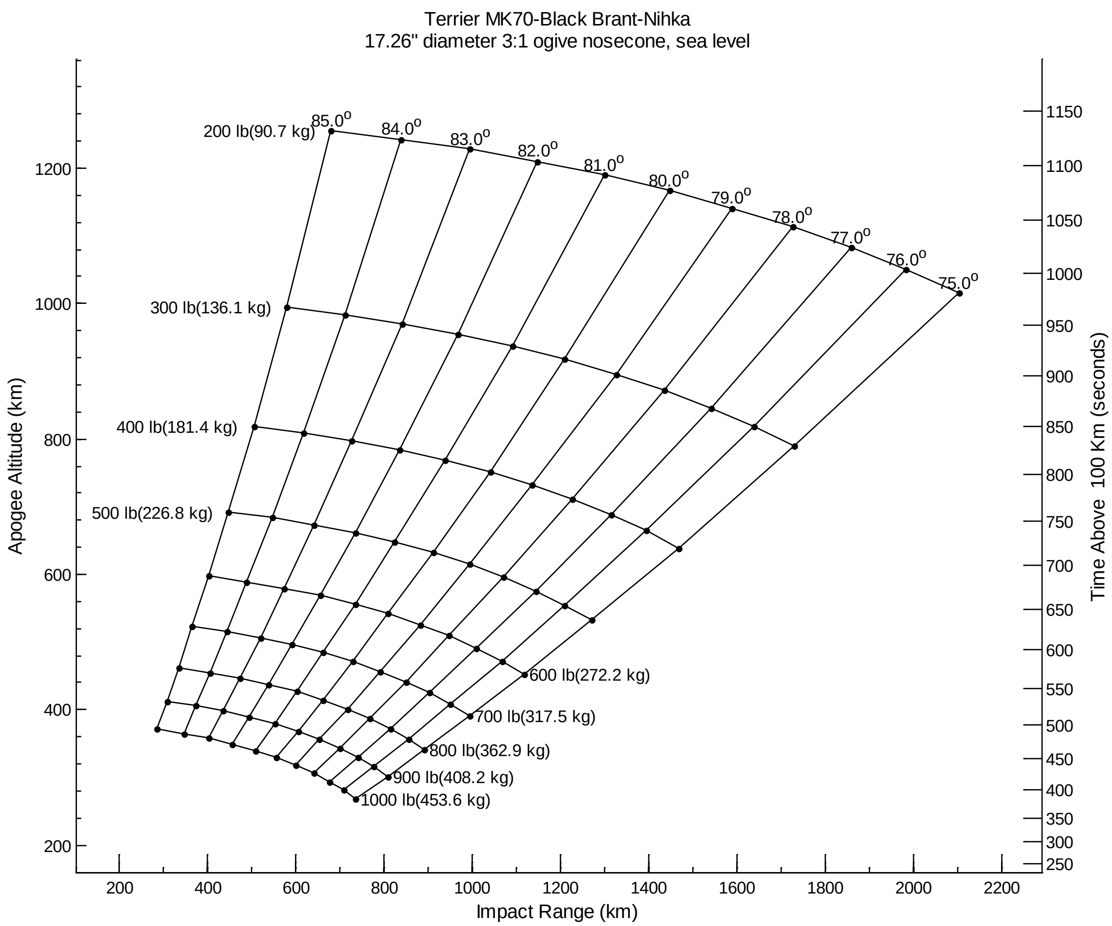


Figure A.6: Black Brant X Launch Vehicle Performance

A.4 Black Brant IX Launch Vehicle (36.XYZ)

General

The Black Brant IX launch vehicle consists of two stages. The first stage is a military surplus, Terrier MK12 or MK70 motor; the second stage is the Black Brant motor with extended exit cone. The Black Brant IX MOD2 (MK70) and MOD3 (MK12) launch vehicles provide a wide range of capabilities for the science community which are not met by other NASA launch vehicles. Figure A.4-1 shows the Black Brant IX launch vehicle.

Figure A.7: Black Brant IX Launch Vehicle

Vehicle Performance

The Terrier booster consists of either a MK12 or MK70 rocket motor with $2.5\ ft^2$ fins arranged in a cruciform. The Terrier has a diameter of 18 inches and is 169 inches long. The Black Brant rocket motor, with extended exit cone, produces an average thrust of 23,317 pounds and has an action time of 27.5 seconds. The diameter is 17.26 inches, and it is 223 inches long. The loaded motor weight, including hardware, is 2,827 pounds which includes 2,223 pounds of propellant. The typical burnout roll rate for the Black Brant IX is approximately 4 cycles per second.

Payload

The standard payload configuration for the Black Brant IX vehicle is 17.26 inches in diameter with a 3:1 ogive nose cone. Bulbous, 22-inch diameter payloads are routinely flown on the Black Brant IX vehicle. Payload weights have ranged from 500 to 2,900 pounds and lengths have ranged from 100 to 350 inches.

Standard sounding rocket subsystems are compatible with the Black Brant IX vehicle which provides flexibility to meet experiment requirements. These modular systems include all attitude control systems, recovery systems, separation systems, and de-spin systems. Guidance systems and thrust termination systems can be added as required.

Performance Graphs

Figures A.4-2(a) and A.4-2(b) are carpet plots of vehicle performance at WSMR and at sea level for the MOD2 variant. Figures A.4-3(a) and A.4-3(b) show the same information for the MOD3 variant.

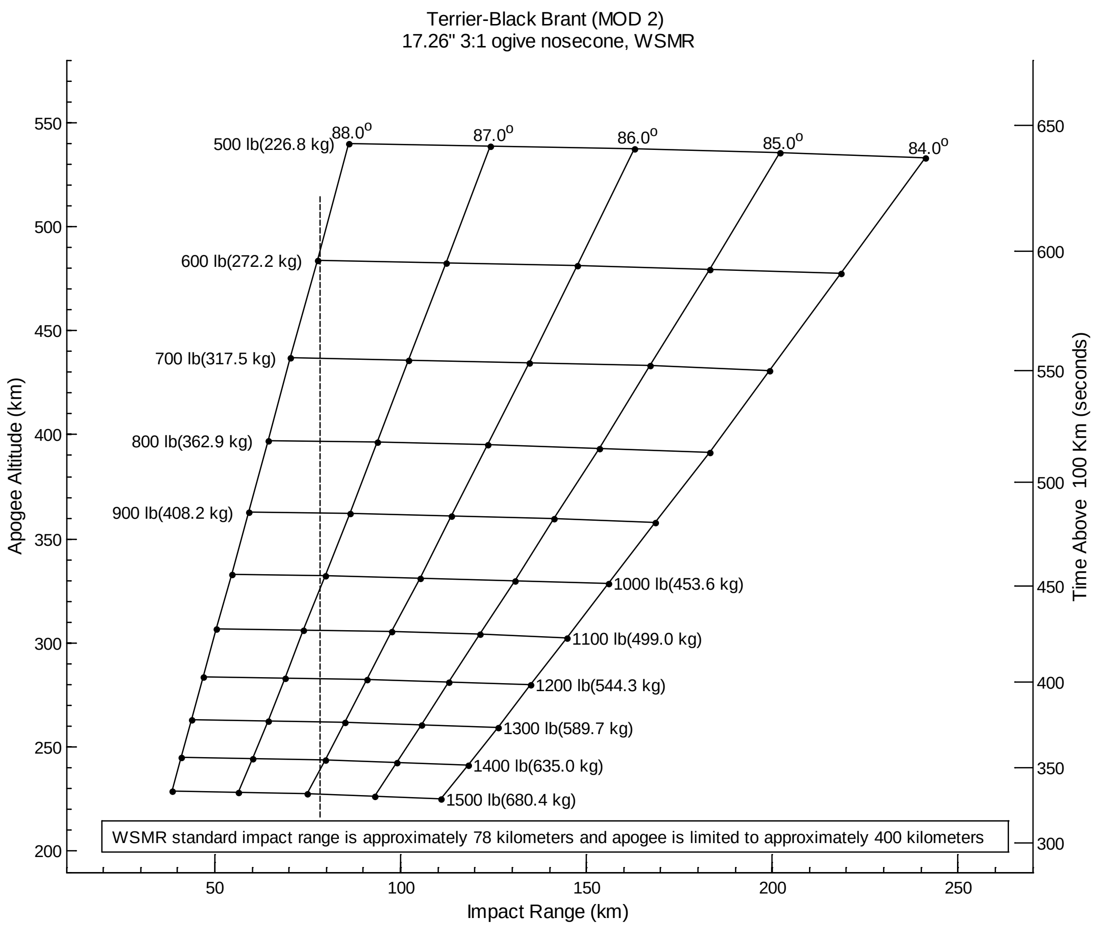


Figure A.8: Black Brant IX (MOD2) Launch Vehicle Performance - WSMR

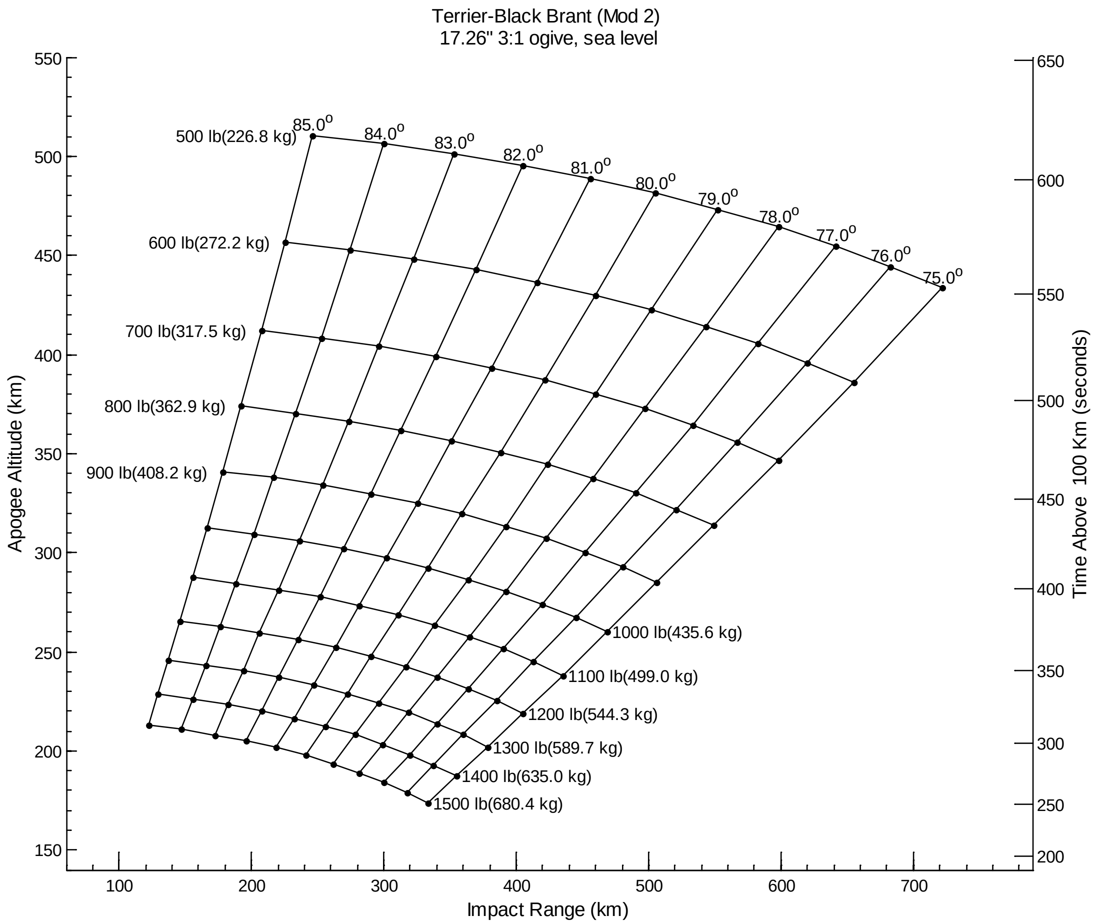


Figure A.9 Black Brant IX (MOD2) Launch Vehicle Performance - Sea Level

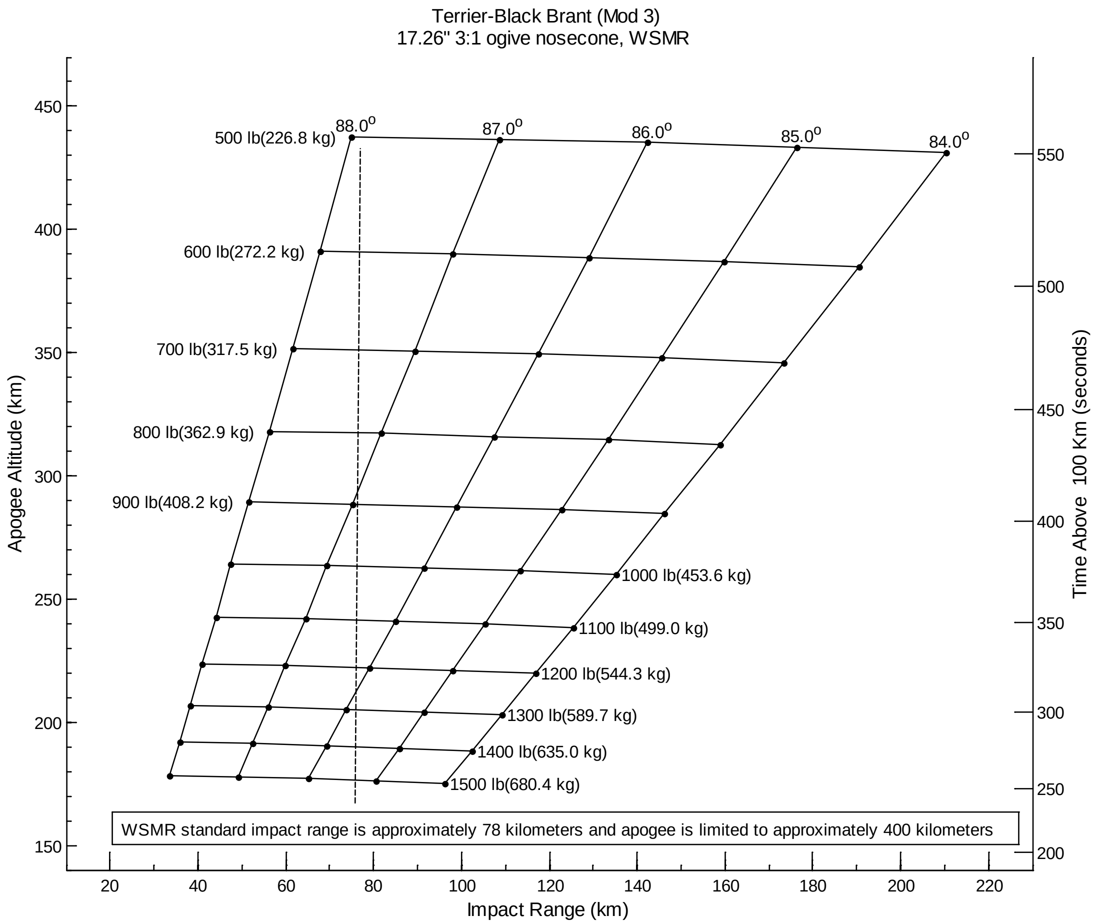


Figure A.10 Black Brant IX (MOD3) Launch Vehicle Performance - WSMR

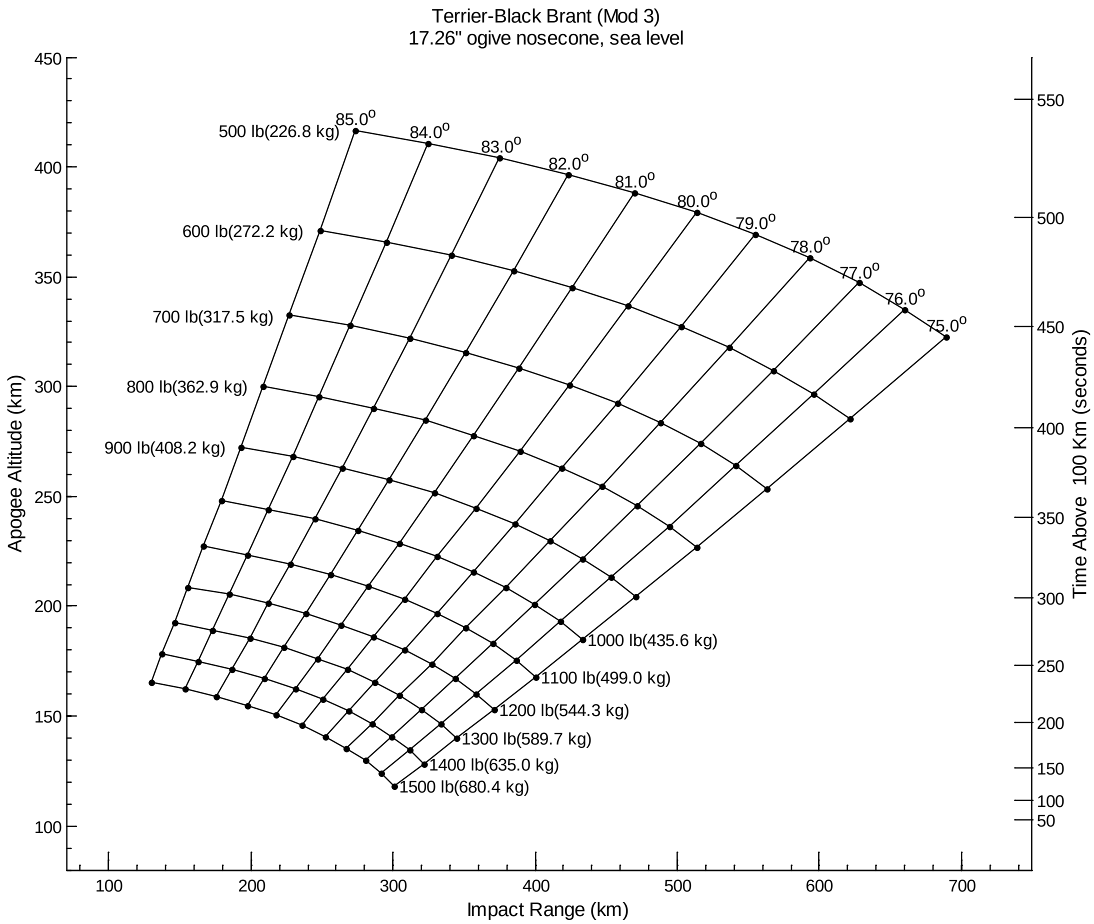


Figure A.11: Black Brant IX (MOD3) Launch Vehicle Performance - Sea Level

A.5 Terrier-Improved Orion Launch Vehicle (41.XYZ)

General

The Terrier-Improved Orion launch vehicle is a two stage, spin stabilized system which utilizes a surplus military Terrier MK12 or MK70 for the first stage booster and an Improved Orion for the second stage. The Terrier motor is 18 inches in diameter and is configured with four, $4.8\,ft^2$ fins arranged in a cruciform. The Improved Orion motor is 14 inches in diameter and 105 inches long. The vehicle can be configured with spin motors to reduce dispersion. The total weight of the launch vehicle, without payload, is approximately 2,850 pounds using a MK12 booster and approximately 3,150 pounds using a MK70 booster. Figure A.5-1 shows the Terrier-Improved Orion launch vehicle.

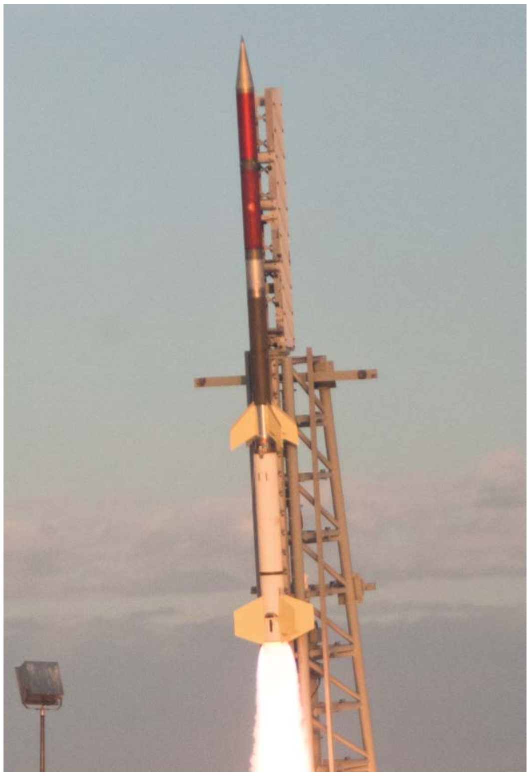


Figure A.12: Terrier-Improved Orion Launch Vehicle

Vehicle Performance

The Improved Orion motor is a surplus military rocket motor with a dual phase propellant system that produces approximately 20,000 pounds of thrust during the first 6 seconds and approximately 4,000 pounds until burnout at 24 seconds. The fins are generally configured to produce a burnout roll rate of 4 cycles per second. The Improved Orion can be equipped with a clamp release or drag separating, load bearing tail can to interface with the Terrier booster.

Payload

Payload configurations supported by this vehicle include 14-inch diameter and bulbous, 17.26-inch diameters. Diameters less than 14 inches are also supported on a per-mission basis. Payload weights range from 300 to 1,100 pounds and lengths range from 70 to 290 inches.

Standard support systems for the 14-inch diameter payloads include aft recovery systems, attitude control systems, various nose cone shapes, and mechanical de-spin. Most 17.26-inch diameter sounding rocket subsystems are compatible with the bulbous payloads which provide flexibility to meet experiment requirements. These modular systems include all attitude control systems, recovery systems, separation systems, and de-spin systems.

Performance Graphs

Performance capabilities for the Terrier, MK12 and MK70, Improved Orion vehicles are shown in Figures A.5-2(a) and A.5-2(b).

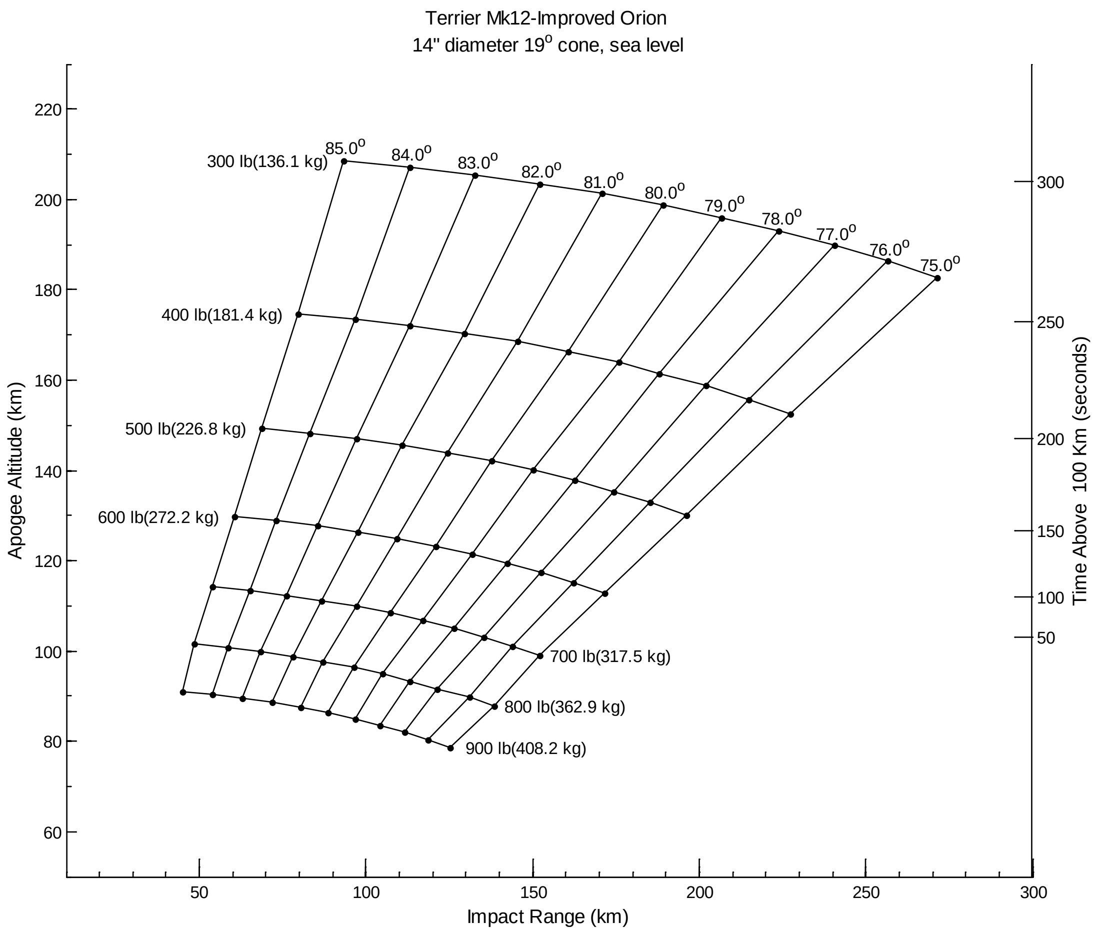


Figure A.13: Terrier MK12 – Improved Orion Launch Vehicle Performance – Sea Level

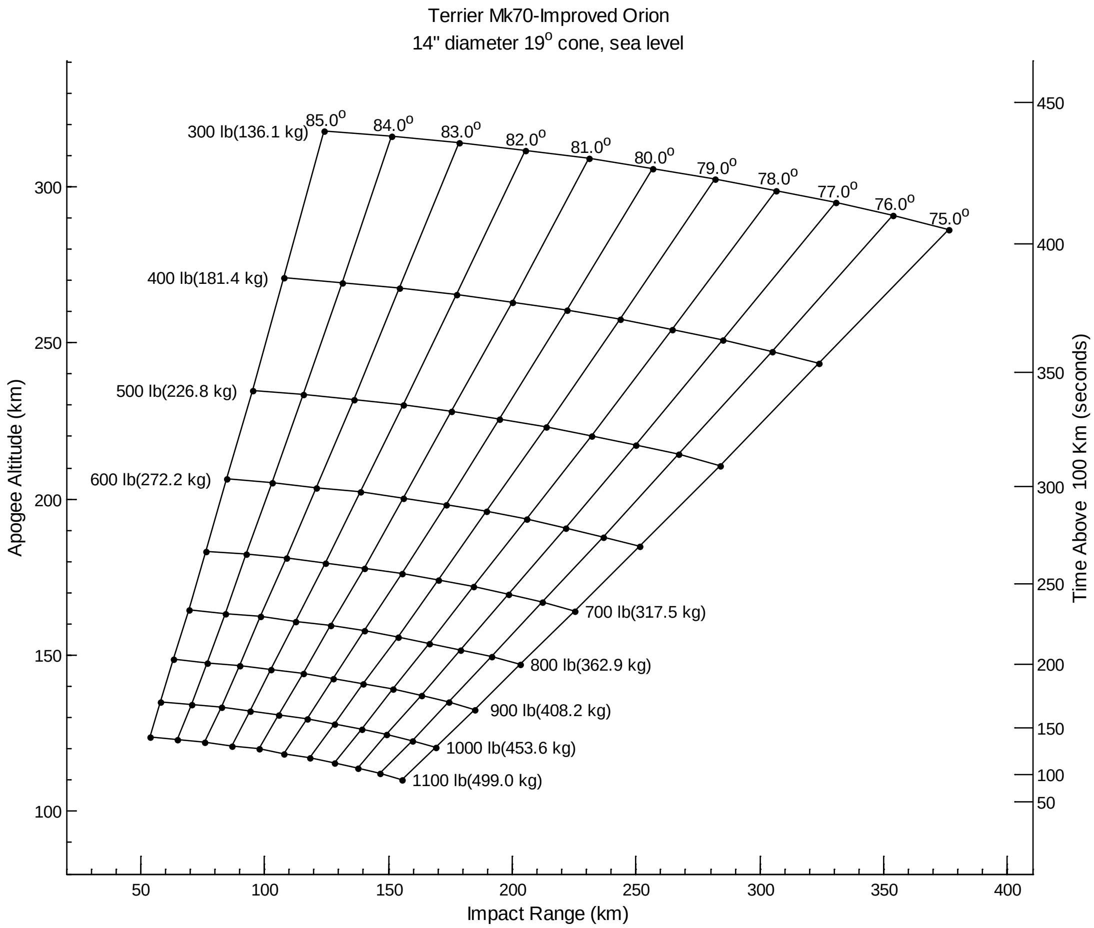


Figure A.14: Terrier MK12 – Improved Orion Launch Vehicle Performance – Sea Level

A.6 Terrier-Improved Malemute Launch Vehicle (46.XYZ)

General

The Terrier-Improved Malemute launch vehicle consists of a two stage, spin stabilized system which utilizes a surplus military, Terrier MK12 or MK70 for the first stage booster and an Improved Malemute for the second stage. The Terrier motor is 18 inches in diameter and is configured with four, $4.8\ ft^2$ fins arranged in a cruciform. The Improved Malemute motor is 16 inches in diameter and 130 inches long. The total weight of the launch vehicle, without payload, is approximately 3,315 pounds using a MK12 booster and approximately 3,615 pounds using a MK70 booster. Figure A.6-1 shows the Terrier-Improved Malemute launch vehicle.

Figure A.15: Terrier-Improved Malemute Launch Vehicle

Vehicle Performance

The Improved Malemute motor is a surplus, military rocket motor with a burn time of 11.7 seconds. The fins are generally configured to produce a burnout roll rate of 4 cycles per second. The Improved Malemute utilizes a drag separated tail can to interface with the Terrier booster.

Payload

Payload configurations supported by this vehicle include 14-inch diameter and bulbous, 17.26-inch diameter systems, typically utilizing an 11-degree total angle nose cone. Payload length and weight limits are not well defined for this vehicle. Payload acceptability is evaluated per mission. Flown payloads have ranged from 600 to 1,000 pounds and lengths have ranged from 180 to 250 inches. Most 14 inch and 17.26-inch diameter sounding rocket subsystems are compatible with the payload which provide flexibility to meet experiment requirements. These modular systems include attitude control systems, recovery systems, separation systems, and de-spin systems.

Performance Graphs

Performance capabilities for the Terrier MK12 and MK70, Improved Malemute vehicles are shown in Figures A.6-2(a), A.6-2(b).

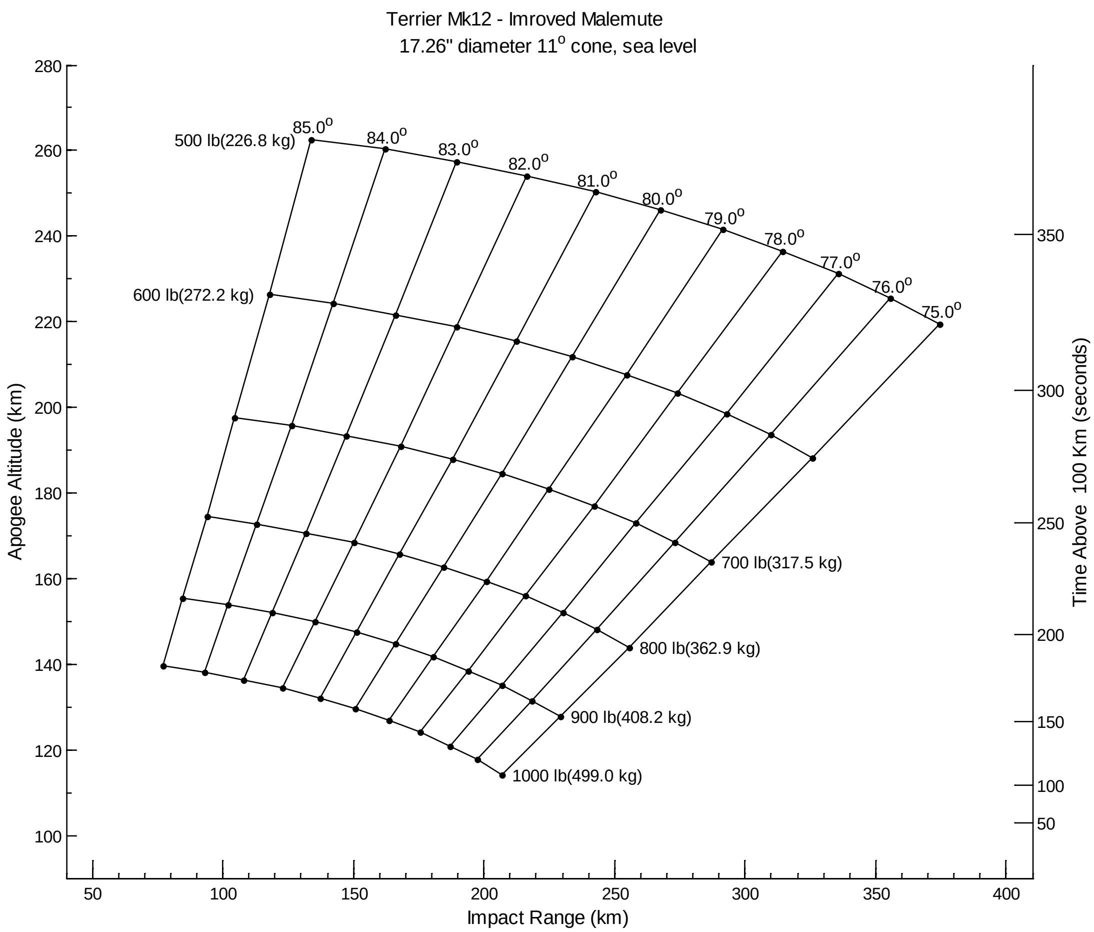


Figure A.16: Terrier MK12 – Improved Malemute Launch Vehicle Performance – Sea Level

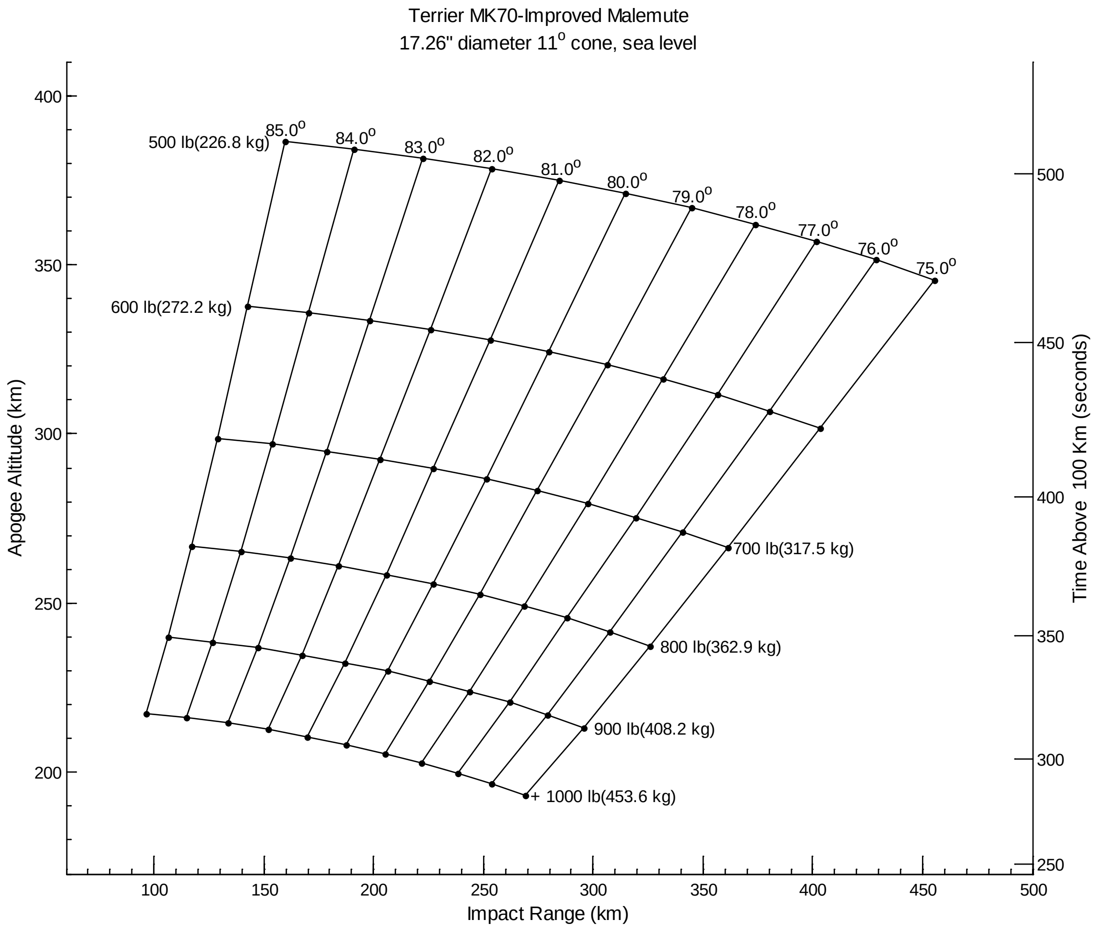


Figure A.17: Terrier MK70 – Improved Malemute Launch Vehicle Performance – Sea Level

A.7 Black Brant XI-A Launch Vehicle (51.XYZ)

General

The Black Brant XI-A launch vehicle uses a three-stage system to carry heavy payloads to high altitudes. The first stage, Talos, and second stage, Terrier MK70, are military surplus motors. The third stage is a Black Brant with extended nozzle. Four spin motors are fixed to the forward end of the Talos to reduce vehicle dispersion. The aft end of the Black Brant tail can is clamped to the Terrier interstage to keep the motors together during the second stage coast period. The launch vehicle, without a payload, weighs approximately 9,562 pounds. Figure A.7-1 shows the Black Brant XI-A launch vehicle.

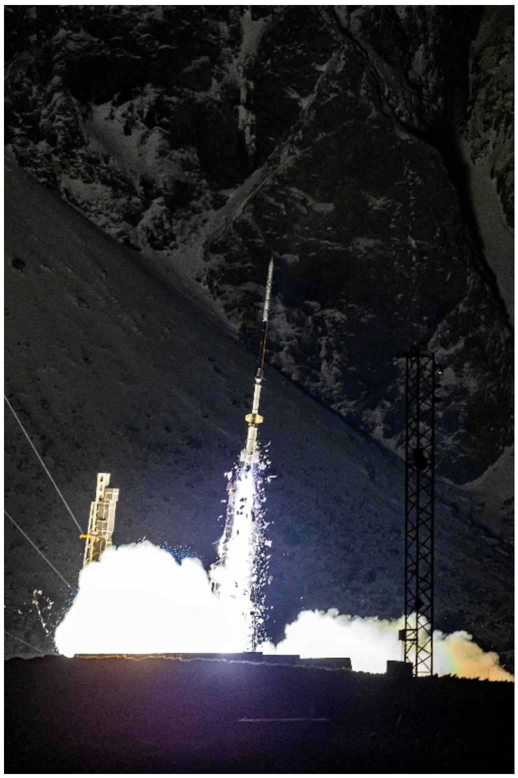


Figure A.18: Black Brant XI-A Launch Vehicle

Vehicle Performance

The Talos motor is 150 inches long with a diameter of 30.1 inches. This length includes a conical adapter to the second stage. Differential drag force causes the expended motor to separate. Four $7.2\ ft^2$ feet fins are arranged in a cruciform to generate a burnout roll rate of about 1.5 cycles per second.

The Terrier MK70 motor is 169 inches long with a principal diameter of 18 inches. The Terrier is clamped to the third stage motor and has an action time of 6.2 seconds. Four $4.8\ ft^2$ fins are arranged in a cruciform configuration to generate a burnout roll rate of about 2 cycles per second.

The third stage motor is the Black Brant with an extended exit cone which produces an average thrust of 23,317 pounds and has an action time of 27.5 seconds. The diameter is 17.26 inches, and it is 223 inches long. The loaded motor weight, including hardware, is 2,827 pounds which includes 2,223 pounds of propellant. Typical burnout roll rate for the Black Brant is about 3.5 cycles per second.

Payload

The standard payload configuration for the Black Brant XI-A vehicle is 17.26 inches in diameter with a 3:1 ogive nose cone. Bulbous, 22-inch diameter payloads have also been flown. Payload length and weight limits are not yet well defined for this vehicle. Payload acceptability is evaluated on a per mission basis. Flown payload weights on this class of vehicle have ranged from 600 to 1,550 pounds and lengths from 150 to 300 inches.
Standard sounding rocket subsystems are compatible with the Black Brant XI-A motor stack which provide flexibility to meet experiment requirements. These modular systems include all attitude control systems, separation systems, and de-spin systems.

Performance Graph

Performance capabilities for the Black Brant XI-A vehicle are shown in Figure A.7-2.

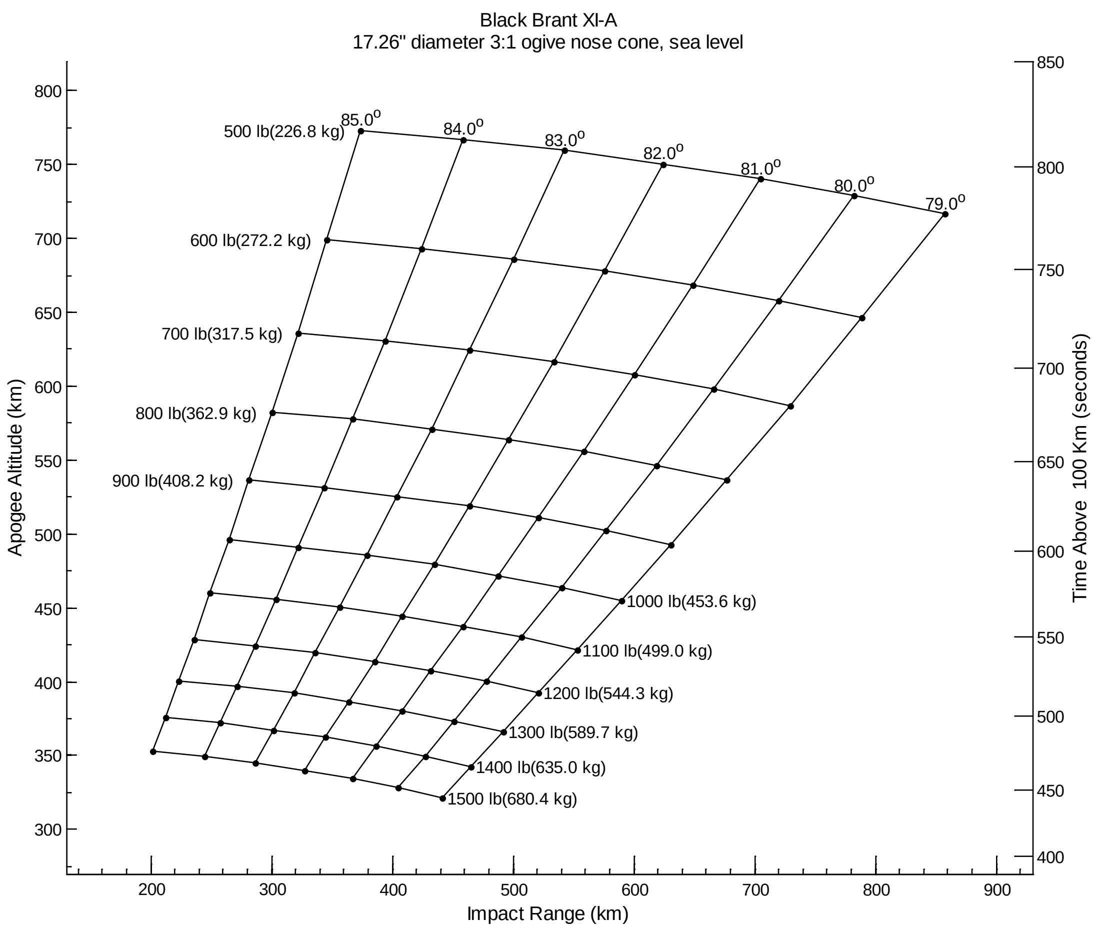


Figure A.19: Black Brant XI-A Launch Vehicle Performance – Sea Level

A.8 Black Brant XII-A Launch Vehicle (52.XYZ)

General

The Black Brant XII-A rocket uses a four-stage system to carry payloads to high altitudes. The first stage, Talos, and second stage, Terrier MK70, are military surplus motors. The third stage is a Black Brant with an extended nozzle; the finless fourth stage, Nihka, is ignited once the vehicle reaches exo-atmospheric conditions. Four spin motors are fixed to the forward end of the Talos to reduce vehicle dispersion. The aft end of the Brant tail can is clamped to the Terrier interstage to keep the motors together during the second stage coast period; the Nihka clamps to the forward side of the Black Brant motor. The launch vehicle, without a payload, weighs approximately 10,510 pounds. Figure A.7-1 shows the Black Brant XII-A launch vehicle.

Figure A.20: Black Brant XII-A Launch Vehicle

Vehicle Performance

The Talos motor is 150 inches long with a diameter of 30.1 inches. This length includes a conical adapter to the second stage. Differential drag force causes the expended motor to separate. Four $7.2\ ft^2$ feet fins are arranged in a cruciform to generate a burnout roll rate of about 1.5 cycles per second.

The Terrier MK70 motor is 169 inches long with a principal diameter of 18 inches. The Terrier is clamped to the third stage motor and has an action time of 6.2 seconds. Four $4.8\ ft^2$ fins are arranged in a cruciform configuration to generate a burnout roll rate of about 2 cycles per second.

The third stage motor is the Black Brant with an extended exit cone which produces an average thrust of 23,317 pounds and has an action time of 27.5 seconds. The diameter is 17.26 inches, and it is 223 inches long. The loaded motor weight, including hardware, is 2,827 pounds which includes 2,223 pounds of propellant. Typical burnout roll rate for the Black Brant is about 3.5 cycles per second.

The fourth stage, Nihka, was developed by Magellan Aerospace specifically for exo-atmospheric conditions. The average thrust is 9,551 pounds with a total impulse of 193,754 pound-seconds. The diameter is 17.26 inches and the loaded motor weighs 907 pounds, of which, 705 pounds is propellant. The burnout roll rate of the Nihka is about 4 cycles per second.

Payload

The standard payload configuration for the Black Brant XII-A vehicle is 17.26 inches in diameter with a 3:1 ogive nose cone. Payload length and weight limits are not yet well defined for this vehicle. Payload acceptability is evaluated on a per mission basis. Flown payload weights on this class of vehicle have ranged from 250 to 1050 pounds and lengths from 90 to 250 inches. The nose cone can be removed before Nihka burn to increase overall performance of the launch vehicle.

Standard sounding rocket subsystems are compatible with the Black Brant XII-A motor stack which provide flexibility to meet experiment requirements. These modular systems include all attitude control systems, separation systems, and de-spin systems.

Performance Graph

Performance capabilities for the Black Brant XII-A vehicle are shown in Figure A.8-2.

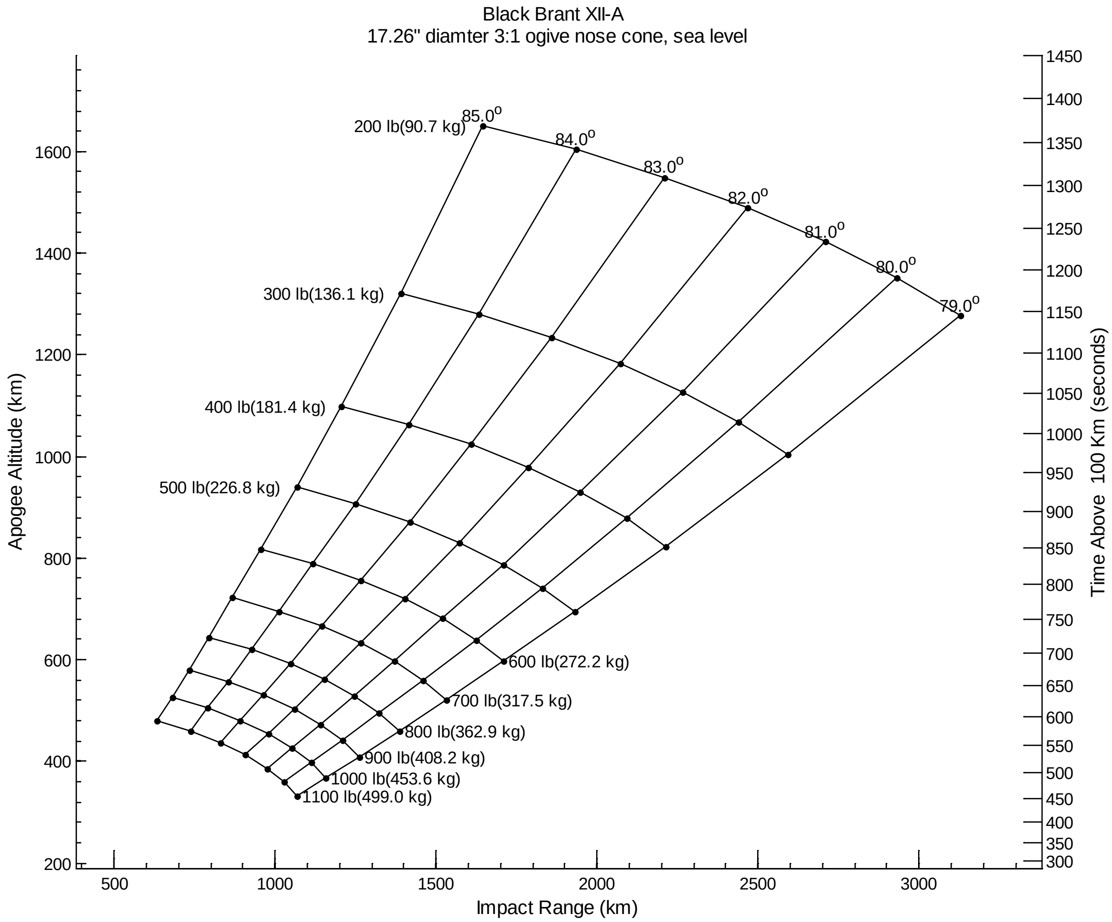


Figure A.21: Black Brant XII-A Launch Vehicle Performance – Sea Level

Appendix B: Sounding Rocket Launch Ranges

B.1 Andøya Space

Introduction

Andøya Space is located near the town of Andenes in northern Norway. The range cooperates with the European Space Agency (ESA) and supports orbital satellite operations as well as sounding rocket and balloon operations, among others.

More details can be found on their web site: http://andoyaspace.no.

Capabilities

The range offers a variety of trajectories for sounding rockets which cover a large area both in latitude and longitude. This, together with an extensive network of ground-based systems, provides flexibility when selecting launch conditions and phenomena to be studied.

The impact areas in the Norwegian Sea set almost no practical limits to impact dispersion for rockets. Rockets have been launched to an apogee of almost 1,500 kilometers, with payload impact at 900 kilometers downrange.

There are two launchers available, both with heated, retractable shelters, capable of launching four stage rockets such as the Black Brant XII-A. Temporary launchers may be installed to support salvos greater than two.

Command uplink is typically not used at this range but could be made available if required.

Facilities

In addition to the launchers mentioned above, the launch area contains a large vehicle assembly area attached to a blockhouse containing a launch control room and a separate area for payload ground support equipment. The launch area is controlled by gate access.

A large payload assembly building is located outside of the launch area as well. The building provides internet access as well as 50 Hz, 120V power. Reconfigurable benches and a crane allow payloads to be assembled and tested prior to staging on the launchers. In addition, three offices are available on the second-floor mezzanine.

A telemetry ground station and several antenna dishes are usually supplemented with mobile assets from Wallops Flight Facility. Remote telemetry sites may be setup in Tromsø or Svalbard depending on mission requirements. Radar tracking is unavailable, so payloads are equipped with GPS and Doppler ranging capabilities.

Wind weighting, flight safety, and launch control are conducted from the second story of the main office complex. A large room is setup for experiment teams on the first floor of the same building. The experimenter's room contains an array of video monitors that can be used to display relevant range and science data. Phones are available to communicate with remote support sites; local network communication equipment is available to communicate with the blockhouse and launch control during launch operations.

Figure B.1: Launch Facilities at Andøya Space, Photo: Kohlbjoern Dahle

Range Interface and Coordination

The primary range interface is the Mission Manager. Since Andøya Space is a foreign range, a Technical Assistance Agreement is required prior to field operations. If the experiment team includes a foreign team member, detailed information is required many months in advance of the start of field operations.

Range support requirements such as purge gas, unique electrical connections, chemicals, etc. must be coordinated well in advance of field operations since a detailed contract must be negotiated and signed with Andoya Space prior to field operations. The Mission Manager works with SRPO representatives to ensure these requirements are included in the contract.

For launch operations, a SRPO representative is present at the range to make a final Go/No-Go call.

Safety and Environment

The winter climate in Andenes is mild compared to Poker Flat Research Range in Fairbanks, Alaska. Temperatures are typically around freezing so snow, rain, and ice are expected. Periods of high winds can make launching from Andøya Space challenging. Depending on seasonal conditions, the entire rocket (vehicle and payload) may be enclosed within a Styrofoam box. The launcher shelter protects the rocket from the elements when the launcher is stowed.

Travel to and from the range can be hazardous during certain seasons. This is offset by a short commute from the town of Andenes and by the roads being cleared or otherwise, serviced, during periods of snow and ice. Rental cars are often equipped with studded tires to increase traction on slick roads. Walking can be hazardous during icy periods and best practices are encouraged. Photography is permitted anywhere on the range.

Visitor Requests

The Mission Manager will need a final list of visitors no later than two weeks prior to the beginning of field operations. Once on site, each visitor will be given an identification card with RFID that allows access to certain areas, such as the payload assembly area or launch area.

Travel & Accommodations

Travel to Andenes from the continental United States is a multi-day process by commercial air. Rental cars are available at the local airport; these must be reserved as the cars are often transported from a larger town. Lodging options consist of houses, hotels, and cabins in the town of Andenes. Andøya Space offers onsite lodging as well. Andenes has several small grocery stores and restaurants. Many of the stores are closed on Sunday.

Shipping

NASA is required to obtain an export license for equipment shipped to the range. Therefore, all experiment hardware and ground support equipment must first be shipped to Wallops Flight Facility to be consolidated into one large shipment. Shipments take at least two weeks to arrive via ship. Smaller FedEx shipments typically take at least one week but can be rushed in as little as two days, depending. It is important to account for spare parts in the original shipment to minimize schedule delays and reduce shipping costs.

B.2 Poker Flat Research Range

Introduction

The Poker Flat Research Range (PFRR) is in the center of Alaska, near Fairbanks, approximately 1 ½° below the arctic circle. As the highest latitude, United States based launch range, it offers unique, domestic opportunities to study polar scientific phenomena. The launch range is managed by the Geophysical Institute, University of Alaska, Fairbanks. Several organizations use the range; the major users are the Department of Defense (DOD) and NASA.

More details can be found on their web site: https://www.pfrr.alaska.edu

Figure B.2: PFRR Aerial View, circa 2019, Photo: Henry Burth

Capabilities

The range is segmented into zones extending north into the Arctic Ocean. This enables land impact trajectories up to 400 miles and water impact trajectories up to 2,800 miles. There are many possible trajectories that may be of interest to customers. There are dispersion limits since there are settlements in some of these zones, such as Veneti, Beaver and Chandalar. PFRR is home to several ground-based scientific observatories and instruments, such as the Neal Davis Science Operations Center, AMISR facility and a LIDAR facility. These instruments, and others in remote locations, can be monitored real time to provide experiment teams critical information about scientific phenomena.

There are currently four launchers installed at PFRR. Each launcher has different capabilities, supporting anywhere from single stage vehicles to four stage vehicles such as the Black Brant XII-A. All launchers are housed within heated, removable shelters.

Command uplink is typically not used at this range but can be made available if required.

Facilities

PFRR occupies some 7,000 acres of land on which is a complex of buildings and ground-based assets to support sounding rocket operations. Many of the buildings are singular in purpose, such as the *Payload Assembly Building, Rocket Assembly Building,* and *Rocket Storage.* Telemetry antenna and ground stations are located adjacent to the launch area on a mountainside and the blockhouse is close to the launch area. All launchers interface to the same blockhouse. Science teams often occupy the science operations center during launch operations.

Range Interface and Coordination

The operations at PFRR are cooperative ventures involving several organizations. For example, WFF is responsible for managing, supporting, and operating radar systems, telemetry systems, timing systems and related equipment at PFRR while the University of Alaska manages, and controls launch operations. It is important that all parties involved in a mission are fully informed on a timely basis on any action which could affect technical arrangements, operations, or scheduling. The NSROC Mission Manager serves as the interface between the experiment team and all range support groups.

For launch operations, a SRPO representative is present at the range to make a final Go/No-Go call.

Safety and Environment

Most of the launch operations at PFRR occur in mid-winter. Temperatures during this season can reach as low as -50° F at PFRR; factoring a wind chill from 50 know winds creates dangerous, if not life-threatening conditions. Exposed skin can freeze in a matter of seconds. Protective clothing is required in winter (Note: PFRR does not provide clothing to visitors. The PI is responsible for providing appropriate cold weather clothing to their teams.) While the facilities at PFRR are heated, there is much work to do done outside, such as walking to vehicles, rigging operations, shelter removal, etc. WFF has a cold weather policy that applies to operations at PFRR.

Weather conditions during other seasons are temperate, with temperatures above freezing from April through October. Except for a few months during the height of summer, there is usually snow on the ground.

Photography is permitted anywhere on the range.

Visitor Requests

The MM will submit a list of visitors to the range approximately two months prior to travel. Once at the range, each visitor will provide a picture as well as contact information, then sign in and out each day. Range access is controlled by an unmanned gate that requires a card that will be distributed on the first day of the visit.

There are no special requirements for foreign nationals.

Travel & Accommodations

Travel to Fairbanks Alaska is by commercial air and usually takes one day from within the continental United States. There are many lodging options in the town of Fairbanks including hotels and rental homes. Rental cars are available at the airport and are seasonally equipped with engine block heaters, battery heaters, and studded tires in the winter. Vehicles need to be plugged in during the winter months.

From Fairbanks, the range is about a thirty-mile drive northeast on AK-2W and AK-6 N. The trip is typically a forty-minute drive over a mountain range. Travel can be hazardous, especially considering the sub-zero temperatures during winter months. The importance of dressing in seasonally appropriate clothing cannot be overstressed. Travel to remote downrange science sites can be arranged through Poker Flat personnel.

Shipping

Being that PFRR is a domestic range, PIs are not necessarily required to consolidate their equipment into a singular WFF shipment. Shipping is accomplished either by air freight or by ground freight, depending on requirements and schedule considerations. The customer is responsible for shipping arrangements and costs for experiment related equipment unless it ships from WFF and is combined with the main payload/GSE shipment. FedEx packages typically take two or three days to arrive from WFF. Freight shipments should be addressed to the following:

Poker Flat Research Range
30 Mile Steese Highway
Fairbanks, Alaska 99712
Hold For: {Mission Number/PI Name}

B.3 Ronald Reagan Ballistic Missile Defense Test Site

Introduction

The Ronald Reagan Ballistic Missile Defense Test Site is in the Kwajalein Atoll which is a part of the Republic of the Marshall Islands. While the test site is often referred to as RTS, this area is generally referred to as "Kwaj". RTS is a US Army installation primarily on the southernmost island of Kwajalein Island. Sounding Rocket operations are typically conducted on the smaller island of Roi-Namur, to the northwest of Kwajalein Island.

More details can be found at the following URL: https://home.army.mil/kwajalein/

Capabilities

RTS covers some 750,000 square miles of Pacific Ocean, atolls, and remote islands. Thus, sounding rocket trajectories vary though most are oriented west or southwest. Impact areas are typically positioned in-between islands and atolls, such as Ujae Atoll and Wotho Atoll. Established ground-based observatories or temporary installations aid customers by providing additional data for studying scientific phenomena in this unique region.

Sounding Rockets are launched from the *Speedball Compound* on the west of Roi-Namur. A single launcher is available with the option to install temporary launchers within the compound, depending on the requirements. These launchers support up to two-stage vehicle configurations. Due to the caustic maritime environment, most NASA assets are temporary – being that they are erected to support a campaign then immediately disassembled and stored or shipped. Temporary fabric shelters can be assembled to protect the launchers and staged rockets.

Command uplink it typically not used at this range but has been used in the past.

Facilities

Speedball encompasses the launch area, the payload assembly building, a bunker used for motor assembly, and several other support buildings. Rocket motors are stored and may be assembled at a remote blockhouse elsewhere on the island. The blockhouse is outside of the compound, about 0.3 km from the launch area. Speedball is fenced and access is controlled by the campaign manager during launch operations.

The payload assembly building (PAB) is a fabric shelter over aluminum framing. The PAB is conditioned, has basic internet access, and 60 Hz, 120 V power. A mobile gantry allows for payload and subsystem manipulation and handling. The floor of the PAB is a rigid plastic over gravel substrate – the floors are not lever to such a degree that alignment procedures can be conducted in the PAB. For critical alignments, the payload is typically relocated to a bunker with a concrete floor. Permanent work benches are not present in the PAB – mission team members often work on folding tables while the payload is either on a payload cart or supported by wooden crates. Office space is limited, mission team members often take meetings in shared blockhouse offices or in their lodging accommodations.

Telemetry assets and meteorological instruments are often supplemented with mobile assets from Wallops Flight Facility. Remote telemetry sites can be setup on Kwajalein Island while remote observation sites can be on many of the surrounding islands, depending on mission requirements.

Wind weighting, flight safety, and launch control functions are conducted from the blockhouse. The mission team, range team, and science team occupy the same space during launch operations. Even so, communication networks are established or installed to effectively coordinate during launch operations.

Despite RTS being an established range, field operations require additional effort and coordination from many groups. This usually requires team members to be deployed to the field for weeks at a time to setup, execute, and disassemble assets.

Figure B.3: Speedball Compound on Roi-Namur, Photo: Henry Burth

Range Interface and Coordination

The primary range interface is the Mission Manager. If the experiment team includes a foreign team member, detailed information is required many months in advance of the start of field operations. All team members traveling to Kwajalein Atoll must receive travel orders from the US Army.

Range support requirements are delegated to teams depending on the requirement. Consumables, such as purge gas and cryogens, must be coordinated, and procured months in advance to ensure timely delivery to Kwajalein. Launcher interfaces must be well established as these must be installed during the campaign. A SRPO representative is present at the range during field operations and to make a final Go/No-Go call.

Safety and Environment

The tropical, equatorial climate of Kwajalein is extreme throughout the year. Daytime temperatures are typically between 80° F – 90° F with high humidity. However, the extreme UV exposure around the equator make the perceived temperature much higher. Dehydration and sun burn are likely to happen if not effectively mitigated.

Travel while on Kwajalein Island and Roi-Namur is limited to walking or biking. Golf carts have been used as a means of transport for team members but are not always available. Residents do not have private vehicles only work-related vehicles are allowed. Vehicles and other equipment can be borrowed from the range if their use supports sounding rocket operations. Most facilities, from lodging, to the mess hall, and the payload assembly building, are within walking distance of no more than 1 km.

Photography is permitted except in controlled areas and of certain assets, such as the airport and runway.

Visitors Requests

Access to Kwajalein is restricted as it is a military installation. Only those who have official business on Kwajalein may disembark. Travel orders from the US Army are required and must be submitted months in advance by the Mission Manager.

Travel & Accommodations

Travel to Roi-Namur is a multi-day process. From the continental Unites States, one must travel to either Guam or Hawaii to board the "Island Hopper". This airline route operates three times per week and provides service to atolls and islands in the Marshall Islands and the Federated States of Micronesia. From Honolulu, the plane lands once in Majuro Atoll before arriving on Kwajalein Atoll. From Kwajalein Atoll, one is taxied via a Fairchild Metro turboprop, known as *Fly Roi,* to Roi-Namur, about a twenty-minute flight.

Commercial lodging is unavailable on Roi-Namur. Mission teams are housed in dormitories for the duration of their stay. Depending on what other activities RTS is supporting, mission team members may be required to share rooms. Lodging arrangements are coordinated through the Mission Manager.

A mess hall provides three meals a day for residents and temporary workers. A small store, The Exchange, sells food and beverages as well as other items such as toiletries and souvenirs. The Exchange on Kwajalein Island has much more inventory than the store on Roi-Namur. There are several recreation facilities including an in-ground saltwater swimming pool, fitness center, 18-hole golf course, library, and bar.

Shipping

Shipping to Kwajalein Atoll is a multi-month process via commercial freight. To simplify logistics, all hardware and ground support equipment needed to execute the campaign is first shipped to Wallops Flight Facility where it is consolidated into Conex containers, then sent as one shipment. Generally, shipments take two months to reach Roi-Namur. In the past, NASA aircraft have been used for shipping though this is infrequent and depends on many factors. Smaller shipments take several weeks to reach Roi-Namur, so it is paramount that spares, and back-up systems are included in the original shipment.

B.4 Svalbard Rocket Range

Introduction

The Svalbard Rocket Range (Svalrak) is operated by Andøya Space. Svalrak is located outside the town of Ny-Ålesund on the island of Spitsbergen in Svalbard, on the 79th parallel. It is considered to the northernmost civilian settlement in the world.

Ny-Ålesund is not officially recognized as a town by the Norwegian government. Instead, the town is owned and operated by Kings Bay, a government enterprise. Kings Bay provides all services (water, power, lodging, air transportation, etc.) in support of arctic research activities and environmental monitoring. The town population varies throughout the year depending on the season – from several dozen people in the winter to over one hundred people in temperate months.

More details can be found on their web site: https://kingsbay.no/

Capabilities

The range offers a variety of trajectories for sounding rockets though most take a southwestern trajectory into the Greenland Sea and Norwegian Sea. Thus, almost no practical limits to impact dispersion are present. With support from remote, ground-based assets in Norway and from the town of Longyearbyen, science conditions can be monitored real time, providing experiment teams critical information about concurrent scientific phenomena, such as the polar cusp.

At the time of this publication, two launchers are installed. Both are within heated, retractable shelters and are generally capable of launching two stage rockets such as the Black Brant IX.

Command uplink is typically not used at this range but could be made available if required.

Facilities

In addition to the launchers, a blockhouse and attached motor assembly building are present at the range. Other buildings in the town of Ny-Ålesund, 1.5 kilometers away, are temporarily used for sounding rocket field operations. For example, heated garages with concrete floors are typically occupied for payload assembly and testing. Other buildings are configured for experiment teams and readout stations as the blockhouse is limited in capacity. Such facilities provide 50 Hz, 120 V power, internet access and communication networks.

Limited telemetry assets, such as antenna dishes and ground stations are supplemented with mobile assets from Wallops Flight Facility. Remote telemetry sites may be setup in Norway or Longyearbyen depending on mission requirements. Radar tracking is unavailable, so payloads are equipped with GPS and Doppler ranging capabilities. Launch roles such as wind weighting and flight safety are typically performed by Andoya Space personnel either at Ny-Ålesund or remotely, in Andenes.

Figure B.4: Launch Facilities at Svalrak, Photo: Henry Burth

Range Interface and Coordination

The primary range interface is the Mission Manager. Since Andøya Space operates Svalrak, and is a foreign range, a Technical Assistance Agreement is required prior to field operations. If the experiment team includes a foreign team member, detailed information is required many months in advance of the start of field operations.

Range support requirements such as purge gas, unique electrical connections, chemicals, etc. must be coordinated well in advance of field operations since a detailed contract must be negotiated and signed with Andoya Space prior to field operations. The Mission Manager works with SRPO representatives to ensure these requirements are included in the contract.

For launch operations, a SRPO representative is present at the range to make a final Go/No-Go call.

Safety and Environment

The climate in Ny-Ålesund varies throughout the year. In the temperate months, average temperatures do not exceed 50° F. In the winter months, temperatures do not exceed freezing. Precipitation is higher in the winter months as well. Due to the arctic terrain and Kongsfjorden, wind is often present. The accumulation of snow and ice throughout the winter makes all travel, either by foot or by vehicle, hazardous. Due to these arctic conditions, the entire rocket (vehicle and payload) is often enclosed within a Styrofoam box. The launcher shelters protect the rocket from the elements when stowed while also improving the working conditions for the mission team.

Another relevant and unique environmental condition is the *Midnight Sun* in summer months and *Polar Night* during the winter. Polar night conditions, when the sun does not rise above the horizon, is an additional challenge to field operations.

A final note about safety. Polar bears are native to Svalbard; their population exceeds 3,000. While polar bears generally avoid human populations, it is not uncommon for polar bears to be sited close to Ny-Ålesund and Svalrak. Outside of town, it is required to carry a firearm for protection from polar bears. The town watch makes carrying a firearm in Ny-Ålesund unnecessary. One must be trained and licensed by Kings Bay to either carry or be issued a firearm. Generally, mission team members do not carry firearms as personnel from Andøya Space are licensed.

Because of the distance to the range from town, the polar bear threat, and the arctic conditions, mission team members are usually driven from town to the range. There are no rental cars available in Ny-Ålesund. Photography is permitted anywhere on the range.

Visitor Requests

As Ny-Ålesund is primarily a research station, there are restrictions on who may access the town. The Mission Manager will submit a list of personnel to Kings Bay to coordinate transportation to Ny-Ålesund. These details need be coordinated several months in advance as lodging is limited. Some local tourism is allowed on a short-term basis (such as to visit the museum and gift shop).

Travel & Accommodations

Travel to Ny-Ålesund from the continental United States is a multi-day process by commercial air. The primary route to Longyearbyen originates in Oslo. From Longyearbyen, a Dornier 228 twin prop shuttles passengers north to Ny-Ålesund. This final flight to Ny-Ålesund is provided by Lufttransport AS. Generally, travel is a three-day journey with destinations being Oslo, Longyearbyen and finally, Ny-Ålesund.

Rental cars are not available in Ny-Ålesund and accommodations are limited to dormitories. There is a small gift shop in town though it has limited hours, usually based on when tourist vessels are docked at the town port. The gift shop offers limited food items, alcohol, and toiletries among souvenirs and Svalbard collectibles.

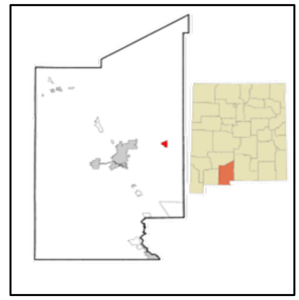
There is no grocery store as all meals are provided by Kings Bay.

Shipping

NASA is required to obtain an export license for equipment shipped to the range. Therefore, all experiment hardware and ground support equipment must be shipped to Wallops Flight Facility first to be consolidated into one large shipment. Shipments take, on average, an additional two to three weeks than those destined for Andenes. Smaller shipments require packages to be intercepted by Andøya Space personnel and rerouted to Ny-Ålesund directly. It is imperative to account for spare parts in the original shipment to minimize schedule delays and reduce shipping costs.

B.5 White Sands Missile Range

Introduction



The White Sands Missile Range (WSMR) is the Department of Defense's largest overland range. It is in southern New Mexico approximately thirty-five miles northeast of Las Cruces, New Mexico, and about seventy miles north-northwest of El Paso, Texas. The climate is semi-arid with unlimited visibility, warm to hot temperatures, and low humidity. Snow is possible during the winter months which can disrupt local traffic and launch operations.

Capabilities

At the time of this publication, there is a single launcher installed at the sounding rockets launch complex (LC-36). A second launcher is being installed and should be functional in the first half of 2023. The launcher(s) are both covered with environmentally controlled, retractable shelters and can launch large payloads with any of the launch vehicles on offer. Most missions utilize the Black Brant IX vehicle. WSMR is a popular destination for launching telescopes with solar or celestial targets; these payloads often gross more than 1,000 lbs and are recovered via military helicopter several hours after launch. A limiting factor to WSMR is dispersion. The width of the range is only about fifty miles wide so apogees are limited to 250 km-300 km. and the width of the range.

NSROC maintains its own data tracking and receiving equipment which is supplemented by numerous WSMR assets. Command uplink is a standard service.

One drawback to sounding rocket missions at WSMR is the quantity of projects with higher national priority. As such, sounding rocket launch dates must be scheduled as soon as possible to reserve the launch window. Still, sounding rocket missions may be moved to accommodate other projects.

Facilities

Sounding Rocket operations are conducted from Launch Complex 36 (LC-36) which consists of a launch area containing a blockhouse and launchers, and the Vehicle Assembly Building (VAB).

All payload testing and assembly takes place in the VAB which has a clean integration lab and two, class 10,000 clean tents and a class 1,000 flow bench. In addition, the VAB contains the telemetry ground station, SPARCS integration lab, magnetic calibration facility, ACS dark room for CACS alignments, payload T&E equipment, conference room, and guest offices. Full-time NSROC employees are stationed at WSMR as it is a frequent launch site for the program.

Range Interface and Coordination

The U.S. Naval Ordnance Missile Test Station sponsors NASA sounding rocket launch activities and coordinates range support. Telemetry support is provided by the New Mexico State University Physical Sciences Laboratory (PSL) using NASA owned equipment. The NSROC Mission Manager will coordinate schedules and support with both groups.

For launch operations, a SRPO representative is present at the range to make a final Go/No-Go call.

Safety and Environment

WSMR has been used as an ordnance and explosives test facility since its inception as a proving ground in 1945 and is one of the world's largest munitions impact areas. All visitors are required to complete Unexploded Ordnance training prior to entering the range.

Photographs are prohibited in all areas except the rocket display near the main entrance. The range provides technical photos, e.g., the staged rocket, team photos, early stages of rocket flight, and recovery. The range can also provide video recordings of the launch. The mission manager coordinates these details with the range.

If the payload requires radioactive sources for in-flight or preflight calibration, a pre-arrival written clearance must be obtained. That should be coordinated well in advance with the Mission Manager.

Figure B.5: White Sands Missile Range

Visitor Requests

PI's need to provide a list of their team members that will support field operations. The Mission Manager will forward the list to the appropriate personnel at WSMR. Visitors will then check in at the security building just outside the main gate to receive a car pass which will allow them access to the range.

Foreign national experiment team members will not be allowed access to the Launch Complex unless a Technical Assistance Agreement is in place for the mission. This process takes many months, so advance planning is required.

Travel & Accommodations

Travel to New Mexico from within the continental United States takes about a day. Team members generally arrive in El Paso, Texas and drive to Las Cruces, New Mexico. Rental cars are available at the airport and there are many hotels in Las Cruces that can be used for long term stays. Lodging is also available on the main post at WSMR. From Las Cruces, it is about a forty-five-minute drive to LC-36.

Shipping

The PI is responsible for shipping the experiment and associated support equipment to WSMR unless it ships from WFF and can be combined with the main payload shipment. Ground freight is the usual mode. Some experiment teams choose to drive their payload and GSE to the range. Small FedEx packages can be shipped to Las Cruces overnight. Freight shipments should be addressed to the following:

NSROC Program/VAB
Vehicle Assembly LC 36, Bldg. N242
White Sands Missile Range, NM 88002
Hold For: {Mission Number/PI Name}

Appendix C: Telemetry Systems

C.1 WFF93 Encoder System

The WFF93 is NSROC's work horse PCM encoder used to support the NASA Sounding Rocket Program. The WFF93 PCM encoder is a general purpose, versatile, re-configurable high rate PCM telemetry system for use where system requirements are subject to change. The format structure is configured by a software program designed for the PC environment. The hardware is configured as a modular, stack-up system with various data modules, which can be added or removed as required. An EEPROM is used as the non-volatile program storage element, allowing the system to be reprogrammed to meet changing mission requirements without hardware disassembly. FCT logic and low power programmable logic devices minimize power consumption. Digital inputs and outputs are FCT/HC or RS422 compatible. Refer to Table C.1 for individual module characteristics.

Table C.1: Individual PCM Module Characteristics - WFF93 PCM System

Module	Description	Data Type	Number of Channels Possible*
Power Supply	+28 V input to ±12 & +5 V output	N/A	N/A
Analog	Analog 0-5 V input range, 10 bits/word maximum resolution, 32 channels per module, 1 A/D converter per module	Analog, Single Ended	Addressing Limit of 992 Channels
Analog	Analog 0-5 V input range, 12 bits/word maximum resolution with readout capability in 2 words for systems with less than 8 bits/word, 8 channels per module, 8 A/D converters per module	Analog, Single Ended with Signal Reference	Addressing Limit of 248 Channels
Analog	Remote differential analog module with 0-5 V or ±15 V input range, 16 bits/word maximum resolution with readout capability in 2 words for systems less than 16 bits/word, 4 channels per module, 4 A/D converters per module, system intended to be remotely located from main WFF93 stack and requires dedicated power supply, data transmitted via digital serial and each analog channel requires a dedicated serial channel in the main PCM stack.	Analog, Differential Input	Addressing Limit of 124 Channels

Control	System clock, timing, formatting, output code generation, and format programming control module	N/A	N/A
Serial	Serial digital single ended or differential input operation, 8 to 16 bits/word, serial word enable, inverted load, gated bit clock timing signal available for each input	Serial Digital	Addressing Limit of 124 Channels
Parallel	Parallel digital single ended input, 8 to 16 bits/word, parallel word enable timing signal available for each input	Parallel Digital	Addressing Limit of 62 Channels
Asynchronous	Asynchronous RS232 or RS422 inputs, 300 to 156K baud rates	Asynchronous	Addressing Limit of 124 Channels
Counter	Event counter single ended or differential input, 8 to 18 bits/word, differential input count rates >10 MHz	Event Counter	Addressing Limit of 248 Channels
Command	Accepts uplink command video and demodulates and synchronizes data, outputs two independent asynchronous channels at rates from 1200 to 19.2K baud, plus parallel command data to uplink command decoder hardware	Uplink Command FSK Video	N/A
Time Event	Time event with single ended or differential inputs, buffered clock-minor frame-major frame-word clock outputs	Time Event	Addressing Limit of 62 Simple Time Event and 62 Alternating Register Time Event Channels
Pre-Modulation Filter	Selectable 1-8 pre-modulation filters with output amplitude adjustability	N/A	N/A

TV Video Digitizer and Compressor	These modules digitize standard NTSC, RS170 or SVHS TV video, compress the digitized data and are converted to MPEG-2 format, and multiplexed with payload PCM data to provide a single composite PCM output signal.	TV Video	Currently Unknown
Clock Driver	Provides 16 programmable, buffered, RS422 compatible differential outputs for 2X bit clock, 1X bit clock, word clock, frame strobe, major frame strobe and PCM code, this module has both DS26C31 standard differential & DS90C31 low voltage differential quad drivers and either can be selected as required	Programmable Clock Driver Outputs	N/A
IMU	Inertial measurement unit that is compatible with either the Litton LN-200 or the Honeywell HG-1700 IMU's. The IMU module accepts SDLC protocol 1-MHz RS422 differential data as well as provides a 1-MHz RS422 differential clock to the IMU for synchronous data transfer	Honeywell or Litton IMU/SDLC	N/A

Note 1: The maximum values are based on theoretical limits. (i.e., number of channels per module times 31, which is the module addressing limit). No one has ever attempted to fly the maximum. Current limitations in the power supply module may determine the maximum number of data modules that can be incorporated in a system.

Note 2: The number of words per major frame is limited to 8,192 words maximum. A document entitled *Pulse Code Modulation Encoder Handbook for Physical Science Laboratory / NMSU Model WFF93 System* fully describes the WFF93 PCM system.

C.2 Mesquito Encoder System

The Mesquito encoder was developed for small form factor telemetry systems which can be programed through an RS232 interface. Like the WFF93 encoder, the Mesquito can be reprogramed to fit mission requirements. The hardware is configured as a modular stack-up system with various data modules which can be added as required. Refer to Table C.2-1 for individual module characteristics.

Table C.2 Individual PCM Module Characteristics – Mesquito Encoder System

Module	Description	Data Type	Number of Channels
Analog	Analog 0-5 V input range, 16 bits/word maximum resolution, 16 channels per module, 2 A/D converters per module	Analog, Single Ended	Currently Limited to 64 Channels Total
Main	System clock, timing, formatting, output code generation, pre-mod filtering and format programming control, uses RS232 control interface	N/A	N/A
Serial (RS422)	Synchronous or asynchronous operation, asynchronous for baud rates from 19.2K to 115.2K baud, synchronous mode is 16-bit words, with serial word enable, inverted load, gated bit clock timing signal available for each input	Serial Digital (RS422)	Currently Limited to 2 Serial Channels
Serial (RS232)	Asynchronous operation only, 1,200 baud to 115,200 baud, three-time event inputs are available	Serial Digital (RS232)	Currently Limited to 2 Asynchronous Serial Channels and 3 Time Events
Power Supply	Aperates with supply voltages from 7-26 V		

C.3 Axon Encoder

Table C.3: Individual PCM Module Characteristics - Axon Encoder System

Module	Description	Data Type
AXN/ADC/401	Programmable input voltage range (±2.4 mV to ±10 V), single ended or differential input, 8 input channels, sample rates up to 50ksps at 16-bit resolution	Analog
AXN/BCU/401	Dual-port bi-directional, full duplex gigabit ethernet, backplane controller	INEA, iNET-X
AXN/BCU/402	Dual-port bi-directional, full duplex gigabit ethernet, backplane controller	INEA, iNET-X, IRIG-106 Ch. 10
AXN/DSI/401	24 differential, discrete, bi-level input channels, each channel as an assigned programmable 32-bit counter	Period, Pulse Width, Duty Cycle, Frequency, Events Since Sample, Events Since Power Up, Events Since Tripper, Samples Since Power Up, Samplers Since Event or Time Since Event
AXN/MBM/402	Two dual redundant MIL-STD-1553 busses for traffic monitoring and recording	iNET-X, IRIG-106 Ch. 10
AXN/UBM/401	Monitors up to 16 RS422/485/232 channels, with bit rates from 300 bps to 10,000,000 bps	Serial RS422/485/232, bits per word, and parity are programmable on a channel-by-channel basis
AXN/ADC/405	24 analog differential ended channels, at a max rate of 20k sps, with a programmable input voltage range	Analog
AXN/ENC/401	Encodes data in an IRIG-106 Chapter 4 PCM stream, dual RS422 outputs up to 40 Mbps, 10 PCM codes, NRZL TTL output up to 16 Mbps, PMF output up to 8 Mbps	IRIG-106 Chapter 4
AXN/EXT/401	Extender card, which allows modules contained in an Axonite remote housing to connect to an Axon chassis	Provides power and data interfaces for one Axonite
AXN/HHS/401	Synchronous serial input, with a differential LVDS interface, utilizing a gated clock and inverted load for timing signals, 4 channels, 8 to 16-bit resolution, other timing signal outputs include Major Frame, Minor Frame, Word Pulse, and Bit Clock	Serial

Table C.4: Individual PCM Module Characteristics - KAM-500

Module	Description	Data Type
KAD/UBM/106	Monitors up to 16 RS422/485/232 channels, with bit rates from 300 bps to 1,000,000 bps	Serial RS422/485/232, bits per word, and parity are programmable on a channel-by-channel basis
KAD/DEC/103	Decommutates up to two IRIG-106 PCM streams in NRZ-L, up to 20 Mbps or BiΦ-L up to 8 Mbps, word length 4-16 bits, up to 4,000 words per minor frame at 16 bits	IRIG-106 PCM
KAD/ENC/106	Encodes data from any KAM-500 module in an IRIG-106 Ch.4 PCM Stream	IRIG-106 Chapter 4
KAD/ADC/111	48 single ended ADC, at 16 bits resolution up to 4ksps	Analog
KAD/BCU/140	Bi-directional, full duplex ethernet backplane controller, dual ethernet output	IENA/iNET-X, PTPv1 client or Grandmaster, PTPv2 client
KAD/DSI/102	Discrete input, programmable counters, 24 channels, 40ns internal resolution	Pulse Counter
KAM/TCG/105	Time-code generator, GPS/IRIG input, battery backup, 1μs time resolution	Time Day: Hour:Min:Sec:MicroSec

Appendix D: Wallops Flight Facility Digital Telemetry System

NSROC can store telemetry data in Chapter 10 format for transferring digitally to customers. For more information about Chapter 10 formatting, please refer to the IRIG-106 *Chapter 10 Digital Recording Standard* document at the following URL:

http://www.irig106.org/docs/106-07/chapter10.pdf

Ulyssix Technologies and Dewesoft

NSROC is currently updating the telemetry hardware in the F10 ground station with the Ulyssix hardware that allows for various data types to be recorded. Dewesoft, the program which runs on the Ulyssix hardware, can record raw data streams in a .D7D file which is proprietary to Dewesoft and is capable of simultaneously recording a .tad file of the data. The benefit of these file types is that the data review is easier because it allows the customer to select a playback start time within the data instead of needing to playback the entirety of the mission log. The Dewesoft program can export the raw data taken from the mission recordings to numerous file types, including MATLAB and Excel formats.

PTP CD-ROM Data Format

This appendix describes the CD-ROM data format generated by the "AVTEC SYSTEMS" Programmable Telemetry Processor for Windows NT (PTP NT). This data format is referred to as "PTP NT" format.

While NSROC currently uses this data type, it is in process of being phased out.

PTP PCM FORMAT

MUX (8 bytes)	**Data Field** (Depends on Frame Length and Word Size)
Format Option #1 File Recorder Format with Record MUX Header enabled	

MUX (8 bytes)	**PB-4** (6 bytes)	**Data Field** (Depends on Frame Length and Word Size)
Format Option #2 File Recorder Format with Record Time Stamp enabled (MUX header is automatically inserted)		

MUX (8 bytes)	**Appended Status** (48 bytes)	**Data Field** (Depends on Frame Length and Word Size)
Format Option #3 File Recorder Format with Record Status enabled. (MUX header is automatically inserted)		

MUX (8 bytes)	**PB-4** (6 bytes)	**Appended Status** (48 bytes)	**Data Field** (Depends on Frame Length and Word Size)
Format Option #4 File Recorder Format with Record Time Stamp and Record Status enabled (MUX header is automatically inserted)			

PTP MUX Header Format

Item	Field Name	Format and Size	Value
1	Header Synchronization	Unsigned Integer (4-bytes)	30030330 Hex
2	Source Module	Unsigned Integer (1-byte)	Equal to the source module number minus 1. For example, if Module 3 sends a buffer to the file recorder, the Source Module field is equal to 2.
3	Header Types	Unsigned Integer (1-byte)	Defines the other header types that follow the MUX Header 0=No Additional Headers 1= PB-4 Time Code 2=Serial Input Appended Status 3=Both PB-4 and Appended Status
4	Next Header Offset	Unsigned Integer (2-bytes)	Offset to the next MUX header in the file relative to the end of the current MUX header. Note that this is a Little-Endian representation, the least significant byte precedes the most significant byte in the file. For example, for 8-bit words and a PCM frame length of 128, the Next Header Offset appears in the file as 80 00 hex (A 6-byte time stamp is normally after the header).
	Total Length	8-bytes	

NASA PB-4 Time Code Format

Item	Field Name	Format & Size	Value
1	Days of Year	Unsigned integer (11 bits)	Range: 1-365
2	Milliseconds of Day	Unsigned integer (27 bits)	Range: 0-86399999
3	Microseconds of a Millisecond	Unsigned integer (10 bits)	Range: 0-999
4	Total Length	6 bytes	

Note: “Days of Year” field uses only the least significant 9 bits of the 11-bit field

PTP Data Field Format

The data field contains the entire PCM minor frame including the frame synchronization pattern and any frame counters. PCM word sizes greater than 8 bits will be right justified in 2-byte words. The most significant byte will precede the least significant byte. If word lengths of 9 to 15 bits are used, the user will have to mask out the uppermost bits in the first word (they will not be zeros). The most significant bit (MSB) precedes the least significant bit (LSB) for each byte. The number of bytes per field is equal to the number of PCM words per minor frame if PCM word length is 8 bits. For PCM word lengths greater than 8 bits, the number of bytes per field is equal to 2 times the number of PCM words per minor frame.

Appendix E: GSFC/WFF Safety Data Requirements

REFERENCE: The GSFC/WFF safety data requirements in this appendix are extracted from the *Goddard Space Flight Center (GSFC) Wallops Flight Facility Range Safety Manual Tailoring for Sounding Rockets Program Office (SRPO)* GSFC-STD-8009T-SRPO Revision C. The customer is responsible for providing the data outlined in this appendix. Vehicle description data is provided by WFF.

Payload Description Data -Hazardous Materials

Pyrotechnic Details - Customers will provide the Mission Manager with schematics and wiring diagrams of all pyrotechnic circuits and other circuits physically or electrically related to pyrotechnics.

For each squib, the minimum all-fire current, maximum no-fire current, recommended firing current, nominal resistance, and RF characteristics (if available) will be provided. A description of the power source will be provided including output voltage and current, battery life, and battery charging details. Scale drawings must be supplied for any payloads with RF transmitters or beacons, showing the location of all pyrotechnic devices in relation to all transmitting antennas. Additionally, schematics, drawings, operation descriptions of pyrotechnic check-outs and monitoring equipment and any other auxiliary equipment will be supplied. The range will be notified of all changes to this information. It is the responsibility of the customer to ensure all drawings, schematics, and procedures are current.

Chemicals & Cryogenics - The customer will provide a description of all chemical systems, including toxicity information and necessary precautions to be taken for storage and handling. The PI is responsible for organizing and submitting the following for each chemical and/or cryogenic system: trade name of the chemical/cryogenic gas or liquid, quantity in gallons or pounds, number of vessels, volume (in^3), operating pressure (psi), applicable Safety Data Sheets pertaining to each individual chemical/cryogenic gas or liquid and the Chemical Abstract Service (CAS#), if applicable. Additional documentation for any cryogenic system under review may be requested.

Pressure Vessels - The customer will provide a description of all pressure vessels used in the payload including design details and test pressures. The PI is required to submit the following: the trade name of all gases used, number of vessels, manufacturer, internal volume (in^3), design burst pressure (psi), proof pressure (psi), maximum allowable working pressure (psi) and materials of construction.

Laser Systems – The customer will provide all technical specifications regarding the laser systems by completing all forms and responding to data requests.

Each custodian and user are required to fill out GSFC 23-35LU to be approved by the Goddard Radiation Safety Officer and Non-Ionizing Radiation Safety Committee. For each wavelength, the PI is required to complete GSFC 23. If the laser is a class 3B or 4, including some visible lasers outdoors, GSFC 23-6L needs to be completed. If the laser will enter navigable air space, the PI may be required to prepare FAA Form 7140.1. If the laser has the potential to impact satellites, the US Space Command Laser Clearinghouse must approve its use.

Transmitters/Beacons – The customer will furnish a Frequency Utilization Request which captures all specifics of the transmitter/beacon to be flown. The PI will provide all RF characteristics of the transmitter/beacon including the following: type of emission, frequency (MHz), type of radiating antenna, gain (dBi), peak radiated power (Watts) and avg. radiated power (Watts).

Radioactive Materials -_For all radioactive materials used at GSFC/WFF involving exposure or possible exposure of personnel, an application will be submitted by the GSFC/WFF to the Nuclear Regulatory Commission for a license granting the GSFC/WFF the authority to:

1. Handle, store, ship, and control sources in use at the GSFC/WFF
2. Establish operational procedures and provide monitoring, dosimetry, and the required records
3. Establish necessary emergency procedures in the event of malfunctions, explosions, or destruct actions
4. Dispose of waste materials

Permission may be granted by the GSFC/WFF for licensed customers to possess and control small calibration or other small sources provided:

1. An operational procedure is submitted for storage, handling, shipment, etc.
2. Records are maintained for all radiation sources, etc.
3. Customers are responsible for the source as stated in the license

The following technical information on radioactive materials must be submitted:

1. Types and numbers of radioactive materials with their current curie content
2. Size, shape, and general characteristics of the radioactive sources
3. Mission of each source
4. Radiation level versus distance from material
5. Container description
6. Shipping and storage container and label description
7. Shipping date and method of shipment
8. Two copies of Nuclear Regulatory Commission's license details
9. Customer's personnel monitoring devices and methods of use (portable survey instruments, personnel dosimeters, film badges, procedures, etc.)
10. Location of radioactive source on research vehicle
11. Customer's representatives who will have responsibility at the range
12. A record of exposure of everyone who will be exposed at the range prior to operations at GSFC/WFF. This should include total exposure, last exposure date, etc.
13. A detailed breakdown of estimated time of source exposure during all build-up, test, and launch operations
14. Procedure for handling and use of external sources during all times exposed
15. All calibration procedures involving the use of exposed radioactive sources

The PI must submit all necessary forms needed before radioactive sources can be brought to GSFC/WFF. Each custodian of a radioactive material is required to submit GSFC 23-35IP, a copy of NRC or State Equivalent License and all procedures.

The PI must determine if the radioactive material is considered a source or a device and whether it will be brought to WFF or WSMR facilities. If the material is to be brought to WFF and the radiation is a device, GSFC 23-6I and GSFC 23-28ID need to be completed. If the material is to be brought to WFF and the radiation is a source, GSFC 23-6I and GSFC 23-28I need to be completed.

The PI needs to determine if the radiation source will be part of the payload to be flown or used as an external calibration source (non-flight).

Appendix F: Science Requirements Data Package (SRDP)

Mission Science Contact: ____
SRDP Document Revision Date/Rev Code: ____________________________

NSROC designs (or modifies) science structures and support systems based on the physical properties, desired flight performance requirements, power, event timing, pyrotechnic, signal handshaking, and channel monitoring/ sampling requirements of the desired science package (payload). The following information is required from Mission Science for each payload (main, mother, daughter, etc.) proposed. A comprehensive data package containing all science information is required well in advance of the DR before a complete design can be established.

Guidelines for completing the SRDP:

- Clearly identify which SRDP items are applicable to the mission.
  - If no additional text is provided in response, requirement will be assumed not applicable.

General

- Launch Date/Window
  - Launch time
- Launch Criteria (Science, weather, other agencies, etc.)

Electrical Engineering

- List of Instruments to be flown.
- Voltage and current requirements for each instrument.
  - Instruments requiring power at lift-off or by timer function in-flight?
  - Nominal voltage required.
  - Minimum and maximum acceptable voltage range?
  - Minimum and maximum current requirement (spanning the entire acceptable min/max voltage range listed above)?
  - Define nominal current "before" & "after" any in-flight events, (e.g., pre-launch current = 500 mA, then experiment current changes to 1A after HV ON event).
  - In-rush current (peak current upon application of power).
  - Current limiting protection provided in the instrument?
  - Are there power sharing issues?
- List of science booms (if any) and micro switch(s) monitor requirements.
- Handshake signal requirements for each instrument (major frame, etc.).
- PCM Matrix requirements
  - System word length (8--16 bits/word, analog data resolution up to 10, 12, or 16 bit/word)
  - Symmetrical or non-symmetrical data sampling requirements
- Complete list of data channels required (All analog data channels must be conditioned to 0 to +5v range).
- Type of channel (synchronous serial, single ended analog, differential analog, counter, parallel, asynchronous serial, time-event) with label names (sciHV, sci15v, etc.).
  - Desired minimum sample rate (SPS) of each channel.
  - Stipulate if symmetrical sampling of the channel is required.

  - Stipulate if contiguous sampling is required.
- For Synchronous Serial:
  - Stipulate multiplexing if used (typical design is one wire-one channel).
  - Stipulate name and sample location of all sensor/sub-channels if multiplexed serial is used.
  - Stipulate single ended, differential 422, or differential LVDS (reflect on pin-out)
  - Provide driver/receiver part numbers used within the experiment for any differential 422 or LVDS interface.
- For Counter:
  - Stipulate single ended or differential 422 (reflect on pin-out)
  - Stipulate reset mode (Reset on each Read, Reset on Overflow, Reset at 1 Hz, or External reset pulse from experiment).
- For Parallel:
  - Stipulate pin for MSB on Parallel
  - Stipulate read, strobe

NOTE:
If not, all channels have been defined allow for the maximum number of spare channels required, again, with desired sample rates.

If the science package includes its own PCM encoding or Analog Baseband system, the following information is required:

- Experiment Provided PCM encoding:
- Define the experiment output signal(s) that will be used to modulate the telemetry transmitter:
  - The experiment PCM encoder output must have an adjustable voltage level and a bipolar signal (equal positive & negative about 0V) for setting the transmitter deviation, when used on telemetry transmitters with an analog modulation input.
  - The experiment PCM encoder must include digital data & clock signals, when used on telemetry transmitters with a digital input.
  - Provide a complete set of experiment PCM encoder parameters (bit rate, bits/words, matrix size, etc.)
- Baseband requirements
  - System must have capability to interrupt the instrument output and send a calibrated tone to the transmitter. This tone should be a calibrated amplitude that will be used for receiver and recorder* calibration set-up. This calibration should "ideally" be controlled from the GSE, through an umbilical line. It is recommended that the experimenter provide output amplitude adjustment capability designed for 75-Ohm load impedance and voltages of up to one-volt RMS.

*Note: An IRIG compatible Chapter 10 recorder with analog channels, will be used for ground station recording of the Baseband experiment signal

Define minimum sample rate to be used for CH10 recording of the baseband signal (Typical sample rates of 20 MSPS, 40 MSPS, and 80 MSPS are possible). Experiment personnel will be responsible for decoding of all CH10 recordings of the baseband signal.

- Wire pin-out of each interface connector.
    - Connector size, type, sex (experiment side, 15, 25, 37-cannon, hard-mounted/pigtail, etc.)
    - Clearly define the reference point when identifying the gender of interface connectors. (Is it "pins" on the experiment chassis and "sockets" on the mating harness? Or is it opposite of this example?)
    - Power and ground requirements (pin 1-28v, pin2- power ground, etc.)
    - PCM timing signals (major frame sync, word clock, etc.) If in doubt as to what signals, narrow the list to the maximum signals needed and include all on the interface connector (after fully defined, use only what is needed on the science side of the connector). Stipulate if data line requires shielded cable, twisted pair, coax type, etc. (ground which end?). All this needs to be defined for each instrument.
- Flight Events list (all timer-controlled science/experimenter events with turn-on requirements such as altitude or time)
    - Stipulate which flight events supply power to the experiment vs flight events that are activated only via "commands".
    - (e.g., some timed events may supply power to a HV supply at a TBD time and consume 500 mA of current. Other timed events may supply a voltage or ground command to switch "ON" a HV supply, yet only consume a few mA when processing the command. This information is required by NSROC EE, so that the design can be implemented correctly).
    - Define the voltage range or activation method for all flight events (unregulated +28V is normally provided for flight events).
    - Stipulate the duration of the flight event. (Should the flight event be momentary, or latched ON for the remainder of flight? If the event is to be momentary, specify the flight event/command duration (in seconds).
    - Altitude protected events
    - Identify any flight events that must be protected from activation on the ground.
    - GSE activated event list (e.g., from umbilical)
    - Identify any "GSE Only" activated commands and the method for activation (e.g., +28V, ground, etc.), and stipulate momentary vs latched commands.
    - Hybrid events that are activated from flight timer as well as GSE.
    - Identify any hybrid events that require activation via GSE, Timer, or Uplink.
    - Special position determination requirements: GPS, Doppler, strobe lights
- GSE/Umbilical requirements
    - External Experiment Switching
    - External Experiment Monitoring
    - Special umbilical requirements (Fiber Optic, RS232, etc.)
    - Special launcher power requirements (3 phase 220 VAC)
- Stray voltage requirements?
    - Identify any exposed voltage restrictions, and acceptable methods of mitigation.
- Data required down to what altitude on down-leg trajectory?
- Define the required data interface from telemetry ground station to Experiment provided GSE.
    - Accept Ethernet packetized data distribution from TM decom?

        - Dewesoft ".NET" Ethernet packetized data distribution?
        - Chapter 10 UDP Ethernet data distribution?
    - RNRZ-L, or NRZ-L data distribution from a bit synchronizer?
- Miscellaneous - Any Special requirements such as an attitude gyro, solar aspect sensor, , magnetometer, or high resolution time tagging should be also be specified. Special testing/calibration such as magnetometer calibration, corona, etc. If the science package structure is to be furnished by WFF accurate dimensions of the instrument(s) in addition to the connector information will be required for hardware placement and wiring of the structure.

Guidance Navigation and Control

- Guidance desired?
- Attitude Control desired?
    - Stabilization: Two (payload spun) or Three Axis?
    - Attitude Requirements:
    - Pointing/rate requirements?
    - Jitter requirements?
    - Drift requirements?
    - Target requirements?
    - Real-time or predictive targeting
    - Required gas purity?
    - Limits on ACS activity?
    - Nozzle location?
    - Experiment sensor to provide control input, describe (not common and significant coordination required)?
- Uplink Command required?
    - Experiment events to be controlled & criticality?
    - ACS pointing / roll commanding?
    - ACS scan pattern?
    - Any in-flight ACS data or generated signals from ACS required? Maneuvering requirements?
- Outgassing requirements?
- ST5000? If yes, confirm compliance with ME83962
- Altitude based event triggering?
- Ejectable Deployment System (chemical deployments)?
    - Deployment altitudes with expected accuracy
    - In the event of a no-eject, what are the desired conditions for chemical release
    - Minimum travel from payload to release point
    - Constellation orientation
    - Ground observation locations
    - Aircraft observation patter

Mechanical Engineering

If Mission Science plans to provide a complete structure (structure, mounted instruments, and skin) the following is required.

- Mechanical Interface
- Mass Properties (Weight, CG, MOI's)
- Special Testing beyond standard tests per ME40280 or deviations
- Required Roll Rates (parameters for Boom deploy, etc.)
- Updated Drawing (includes openings-doors, etc.)
- Metal Finish required
- Sensor Fields of View and keep-out zones
- Shutter Door required and required orientation.
- Crush Bumper
- Experiment pyrotechnics
- Magnetic Cleanliness
- Out-gassing requirements (limitations of materials used and proximity)
- Details of all rail interfaces (payload external to launcher) and Ground Support Equipment used while on the pad (vacuum, cryogenic, etc.)
- Deployable Booms
  - For Flight Safety purposes: Provide material, cross section dimensions, and assessment of any weak points on the booms for downrange impact dispersions.

If NSROC will provide the structure and skin the following is required.

- All physical Characteristics
  - Instrument(s) size, dimensions, and Weight & CG, drawings w/ connector locations, clearance required for connectors, mounting hole patterns & sizes, (Boxes, Booms, etc.) (Solid Models esp. SolidWorks, are a plus and preferred)
  - Desired location of instruments (accessibility/doors)
  - Out-gassing requirements (limitations of materials used and proximity)
  - Experiment interfaces (umbilicals, nozzles, and access ports, etc.)
  - Acceptable science view characteristics
- Separation velocities (payload bodies, ejectables)
- Special Testing beyond standard tests per ME40280 or deviations
- Required Roll Rates (parameters for Boom deploy, etc.)
- Metal Finish required
- Sensor Fields of View and keep-out zones
- Shutter Door required, and required orientation, and specific metal finish, and any custom modifications for ports.
- Crush Bumper
- Chemical Ejectable Deployment System
  - EDS Systems on separate payload body from other instruments?
  - # of total ejectables? # of Ba/Sr/CuO Ampules? # of TMA Ampules?
- SWARM Electronic Ejectables
  - # of ejectables?
  - Rocket or Spring ejected?
  - Targeted separation velocity?

  - GPS? (Not compatible with Rocket ejection)
- Experiment pyrotechnics
- Magnetic Cleanliness
- Details of all rail interfaces (payload external to launcher) and Ground Support Equipment used while on the pad (vacuum, cryogenic, etc.)

If NSROC will provide the skin section only the following is required.

- Mass Properties of the hardware and structure (Wt. & CG
- Mechanical interface with skin section
- Experiment interfaces (umbilicals, nozzles, and access ports, etc.)
- Acceptable science view characteristics
- Separation velocities (payload bodies, ejectables)
- Special Testing beyond standard tests per ME40280 or deviations
- Required Roll Rates (parameters for Boom deploy, etc.))
- Metal Finish required
- Sensor Fields of View and keep-out zones
- Shutter Door required, and required orientation, and specific metal finish, and any custom modifications for ports. Crush Bumper?
- Chemical Ejectable Deployment System
  - EDS Systems on separate payload body from other instruments?
  - # of total ejectables? # of Ba/Sr/CuO Ampules? # of TMA Ampules?
- SWARM Electronic Ejectables
  - # of ejectables?
  - Rocket or Spring ejected?
  - Targeted separation velocity?
  - GPS? (Not compatible with Rocket ejection)
- Experiment pyrotechnics
- Magnetic Cleanliness
- Out-gassing requirements (limitations of materials used and proximity)
- Details of all rail interfaces (payload external to launcher) and Ground Support Equipment used while on the pad (vacuum, cryogenic, etc.)

Performance Analysis
- Trajectory Information
- Desired Apogee Altitude
- Desired Time above a given Altitude
- Desired overflight of a location
- Irregular bodies or other features that may create dynamic issues in flight?
- Special Timeline requirements related to payload/vehicle (de-spin, motor separation, etc.)?
- Special Impact range requirements
- Post-flight attitude data required?
  - Solution time synchronized?

Vehicle Systems

- Launch range
- For instruments exposed by nosecone deploy: Will the instruments being in the wake of the nosecone pose a problem? (drives use of Radially Ejecting Ogive System)
- Recovery required
    - Special recovery considerations (timing, hazards, personnel, etc.)

The following information is required if Mission Science desires specific test or range facility support.

- Any required dates for Science Integration & Testing (I & T)?
- Post-I&T refurbishment time requirements prior to field operations?
- What are the Hazardous Material requirements?
- What are the Ground Support requirements (payload handling) during I & T & launch range?
    - Clean room / Tent environment for assembly / testing?
    - Purging gasses (Type of Gas, % Purity and amount required) for assembly / testing?
    - Cooling gasses / cryogenic liquids (Type of Gas/Liquid, % Purity and amount required) for assembly / testing?
    - Will Science provide their own pneumatic equipment? (needs to be certified and approved)
    - Special Power Requirements (A.C. / D.C.)?
    - Special Environmental Testing Facilities required (Magnetometer Calibration, Vacuum testing of system(s) / components, boom / sensor deployment testing, etc.)?
    - Special GSE requirements?
    - Special Payload Environmental Control Requirements, to include temperature and humidity, such as boxing of the payload for temperature control, during Pre-launch and Launch operations?
        - Temperature and/or humidity monitoring requirements.
    - Payload elevation requirements during testing and while on the launch rail.
    - Requirements for handling of Non-launched / Aborted Launch Mission flight hardware, hazardous materials?
    - Computer / Communications Requirements?
- Identify Payload Systems that cannot be powered off or shutdown during arming operations prior to launch (~2 hrs.).
- Identify Payload Systems that will be powered during transportation to the launcher.

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Appendix G: Principal Investigator's Data Package for Mission Initiation Conference

- **Description** of scientific objectives and list of specific instruments.
- **History** of the experiment including number of times the experiment or a similar one has flown, giving flight history and any modifications of previously flown payloads.
- **Outline diagram** with station numbers including weights, center of gravity, moment of inertia data, deployable elements, doors, booms, nose cones, etc., if available.
- **Structures and Mechanisms**
    - Payload Structure
    - Payload Housing
    - Openings
    - Doors
    - Booms - Antennas
    - Special Mechanisms
    - Hardware and Structures to be Fabricated at WFF.
- **Outgassing requirements**, magnetic material sensitivity, radio frequency interference susceptibility.
- **Time/Altitudes** of all experiment related events.
- **Instrumentation – Telemetry**
    - Power Required
    - Quantity and Bit Rate of RF Links
    - Transmitter(s)
    - Antenna
    - Commutator(s)
    - Squib Circuits
    - Monitors
    - Aspect Sensors
    - Magnetometers
    - Accelerometer
    - Radar Beacon
    - Power
    - Uplink
- **Vehicle**
    - Performance
    - Minimum Altitude Required
    - Coning Angle Acceptable
    - De-spin
    - Special Systems
    - Type Nose Cone
    - Pointing Requirements
- **Flight qualification/operational status** of experiment's subsystems, new flight items or deviation from previously qualified systems.

- **Restrictions, precautions, special requirements, limitations** for environmental testing of integrated payload.
- **Range Support**
    - Telemetry Ground Station
    - Tracking Requirements
    - Special Ground Support Equipment: Clean Tent, Temp Constraints, Purge, etc.
    - Recovery
- **Launch Conditions**
    - Launch Range
    - Time of Day
    - Azimuth
    - Launch Angle
    - Window
    - Special Conditions – Restraints – Go/No-go Criteria
- **Unique or special range requirements** including special checkout or support equipment. (Long lead time items)
- **Radioactive Sources** - Payload/Calibration or Hazardous Materials
- **List of Specific Minimum and Comprehensive Success Criteria**. If the flight is part of a launch series, criteria must be specified for each individual launch. Requirements should include such things as apogee, time above altitude, pointing, coning, roll rate, etc., as appropriate.
- **List of Contacts**, Titles, Address, Telephone Numbers.

Appendix H: Principal Investigator's Data Package for a Requirements Definition Meeting

(This package is a follow-up to information initially provided by Mission Science in the MIC Questionnaire.)

Mission Science Contact: ____

NSROC designs (or modifies) science structures and support systems based on the physical properties, desired flight performance issues, power, event timing, pyrotechnic, signal handshaking, and channel monitoring/ sampling requirements of the desired science package (payload). The following information is requested from Mission Science for each payload (main, mother, daughter, etc.) proposed. A comprehensive data package containing all science information is requested before a complete design can be established.

Electrical Engineering

- List of Instruments to be flown
- Voltage and current requirements for each instrument
    - Instruments requiring power at lift-off or by timer function?
    - Current limiting protection provided in the instrument?
    - Are there power sharing issues?
- List of science booms (if any) and micro switch(s) monitor requirements
- Handshake signal requirements for each instrument (major frame, etc.)
- Matrix requirements
    - System word length (8--16 bits/word, analog data resolution up to 12 bit/word)
    - Symmetrical or non-symmetrical data sampling requirements
- Complete list of data channels required (All analog data channels must be conditioned to 0-5v)
    - Type of channel (serial, analog, counter, parallel, asynchronous, time-event) with label names (sciHV, sci15v, etc.)
    - Desired minimum sample rate (SPS) of each channel
    - Stipulate if symmetrical sampling of the channel is required
    - Stipulate if contiguous sampling is required
    - For Serial:
        - Stipulate multiplexing if used (typical design is one wire-one channel)
        - Stipulate single ended or differential (reflect on pin-out)
    - For Counter:
        - Stipulate single ended or differential (reflect on pin-out)
        - Stipulate reset mode
    - For Parallel:
        - Stipulate pin for MSB on Parallel
        - Stipulate read, strobe

If the science package includes its own encoding or Baseband system, the following information is required:

- The encoder output must be adjustable for deviation setting
- Baseband requirements:

  System must have capability to interrupt the instrument output and send a calibrated tone to the transmitter. This tone should be a calibrated amplitude that will be used for receiver and recorder* calibration set-up. This calibration should be controlled from the GSE, through an umbilical line. It is recommended that the experimenter provide output amplitude adjustment capability designed for 75-Ohm load impedance and voltages of up to one-volt RMS.

- Wire pin-out of each interface connector
  - Connector size, type, sex (experiment side, 15,25,37-cannon, hard-mounted/pigtail, etc.)
  - Power and ground requirements (pin 1-28v, pin2- power ground, etc.)
  - PCM timing signals (major frame sync, word clock, etc.) If in doubt as to what signals, narrow the list to the maximum signals needed and include all on the interface connector (after fully defined, use only what is needed on the science side of the connector). Stipulate if data line requires shielded cable, twisted pair, coax type, etc. (ground which end?). All of this needs to be defined for each instrument.
- Flight Events list (all timer-controlled science/experimenter events with turn-on requirements such as altitude or time)
- Altitude protected events
- ACS controlled or up-link command-controlled requirements
- Special position determination requirements: GPS, Doppler, strobe lights

NOTE: A Data Tape model DTR-6, -8, or -16 recorder must be used for Baseband recording.

NOTE: If not all channels have been defined allow for the maximum number of spares

channels required, again with desired sample rates.

- GSE/Umbilical requirements
  - External Experiment Switching
  - External Experiment Monitoring
  - Special umbi requirements (Fiber Optic, RS232, etc.)
  - Special launcher power requirements (3 phase 220 VAC)
- Miscellaneous:

Any Special requirements such as an attitude gyro, solar aspect sensor, lunar aspect, magnetometer, or high-resolution time tagging should also be specified. Special testing/calibration such as magnetometer calibration, corona, etc. If the science package structure is to be furnished by WFF accurate dimensions of the instrument(s) in addition to the connector information will be required for hardware placement and wiring of the structure.

Guidance Navigation and Control

- Guidance desired?
- Attitude Control desired?
  - Stabilization: Two (payload spun) or Three Axis?

- Attitude Requirements:
    - Pointing/rate requirements?
    - Jitter requirements?
    - Drift requirements?
- Uplink Command required?
    - Instrument generated signal Interface to ACS required?
    - Maneuvering requirements?
- Outgassing requirements?
- Nozzle location or firing restraints?

- Post-flight attitude data required?

Mechanical Engineering

If Mission Science plans to provide a complete structure (structure, mounted instruments, and skin) the following is required.

- Mechanical Interface
- Mass Properties (Weight, CG, MOI)
- Special Testing
- Required Roll Rates (parameters for Boom deploy, etc.)
- Updated Drawing (includes openings-doors, etc.)
- Metal Finish required
- Shutter Door Required
- Crush Bumper
- Experiment pyrotechnics
- Magnetic Cleanliness

If NSROC will provide the structure and skin the following is required.

- All physical Characteristics
    - Instrument(s) size, dimensions, and Weight & CG, drawings w/ connector locations, clearance required for connectors, mounting hole patterns & sizes, (Boxes, Booms, etc.)
    - Desired location of instruments (accessibility/doors)
    - Out-gassing requirements
    - Experiment interfaces (umbilicals, nozzles, and access ports, etc.)
    - Acceptable science view characteristics
- Separation velocities
- Special Testing
- Required Roll Rates (parameters for Boom deploy, etc.)
- Metal Finish required
- Shutter Door Required
- Crush Bumper
- Experiment pyrotechnics
- Magnetic Cleanliness

If NSROC will provide the skin section only the following is required.

- Mass Properties of the hardware and structure (Wt. & CG
- Mechanical interface with skin section
- Experiment interfaces (umbilicals, nozzles, and access ports, etc.)
- Acceptable science view characteristics
- Separation velocities
- Special Testing
- Required Roll Rates (parameters for Boom deploy, etc.))
- Metal Finish required
- Shutter Door Required
- Crush Bumper
- Experiment pyrotechnics
- Magnetic Cleanliness
- Outgassing requirements.

Performance Analysis

- Trajectory Information
- Desired Altitude
- Desired Time above a given Altitude
- Apogee
- Dynamic issues?
- Timeline issues?
- Impact range

Vehicle Systems

- Launch range
- Ground support requirements (payload handling)
- Thermal requirements on launcher
- Altitude
- Recovery required

The following information is required if Mission Science desires specific test or range facility support:

- When will Science prefer to integrate? Where?
- What are the Hazardous Material requirements?
- Are there Thermal requirements on launcher?
- What are the Ground Support requirements (payload handling) during I & T & launch range?
    - Clean room environment for assembly / testing?
    - Purging gasses (Type of Gas, % Purity and amount required) for assembly / testing?
    - Cooling gasses (Type of Gas, % Purity and amount required) for assembly / testing?
    - Special Power Requirements (A.C. / D.C.)?

- Special Environmental Testing Facilities required (Magnetometer Calibration, Vacuum testing of system(s) / components, boom / sensor deployment testing, etc.)?
- Special GSE requirements?
- Special Payload Environmental Control Requirements (boxing of the payload for humidity and temperature control) during Pre-launch and Launch operations?
- Requirements for handling of Non-launched / Aborted Launch Mission flight hardware, hazardous materials?
- Computer / Communications Requirements?

Appendix I: Principal Investigator's Data Package for a Design Review

Vehicle No.______________________________

- Brief description of experiment.
- Block diagram and all pertinent schematics and detailed drawings.
- Outline diagram including estimated weights, center of gravity, moments of inertia (best data available).
- History of experiment including flights, problems and failures, number of times experiment or similar one has flown, giving flight number.
- Specific criteria (times/altitudes, etc.) of all experiment related events.
- Pointing requirements including:
    - ACS
    - Coning
    - Spin
    - Azimuth
    - Elevation
- Launch window requirements.
- Comprehensive mission success criteria, include a statement of vehicle performance, i.e.___, lb. to ___KM apogee or, ___lb., above ___KM for ___seconds,
- Minimum success criteria, include a statement of vehicle performance, i.e., ___lb. to ___KM apogee or, ___lb. above ___KM for seconds.
- Support requirements including special considerations, i.e., real-time readouts, gases, environmental control.
- Flight qualification/operational status of experiment's subsystems. Where there are any new flight items or deviations from previous qualified system, include all pertinent documentation.
- Describe all redundant systems.
- List history of items to be flown
- Principal Investigator's go-no-go launch criteria (preliminary minimum success).
- List experiment/instrumentation interface requirements including power, control/timing, data, power bus protection, etc.

Appendix J: Principal Investigator's Data Package for a Mission Readiness Review

Vehicle No. ______________________________

- Description of experiment.
- Block diagram and all pertinent schematics and detailed drawings.
- Power requirements including short circuit protection and corona precautions.
- Outline diagram including weights, center of gravity, moments of inertia data.
- History of the experiment, flights, problems, failures.
- Specific criteria (times/altitudes, etc.) of all experiment related events.
- Pointing requirements including:
    - ACS
    - Coning
    - Spin
    - Azimuth
    - Elevation
- Launch window requirements.
- Comprehensive mission success criteria; include a statement of vehicle performance, i.e., ___lb. to ___KM apogee or, ___lb. above ___KM for ___seconds.
- Final minimum success criteria; include a statement of vehicle performance, i.e., ___lb.to ___KM apogee or, ___lb. above ___KM for ___seconds.
- Support requirements including special considerations, i.e., real time readouts, gases, environmental control.
- Flight qualification/operational status of experiment's subsystems. Were there are any new flight items or deviations from a previous qualified system, include all pertinent information, documentation, and test data.
- Describe all redundant systems and list how they are tested.
- Principal Investigator's master field check-off list with designated responsibilities.
- Principal Investigator's Go-No-Go launch criteria
- List any special requirements in the event of a scrubbed mission
- List any post-flight requirements.
- Provide a testing and integration malfunction log including corrective actions for the experiment system/subsystems.
- List of all discrepancies still in the system to be corrected.
- Summarize all suspect items in the experiment system/subsystem.

Acronyms

ACS	Attitude Control System
ETD	Engineering and Technology Directorate
AIB	Anomaly Investigation Board
ALVS	Aft Looking Video System
ASI	Agency Safety Initiative
BGS	Boost Guidance System
CACS	Celestial Attitude Control System
CDR	Critical Design Review
CG	Center of Gravity
CSS	Coarse Sun Sensors
CUS	Command Uplink System
DMARS	Digital Attitude Reference System
DNMACS	Digital NSROC Magnetic Attitude Control System
DRCS	Data Reduction Computer System
ECS	Engineering Computer System
EEPROM	Electronically Erasable Programmable Read-only Memory
FAA	Federal Aviation Administration
FCT	Fast CMOS Technology
FOG	Fiber Optic Gyro
FRP	Flight Requirements Plan
FRP	Flight Requirements Plan
FRR	Flight Readiness Review
FSK	Frequency Shift Keying
FSP	Flight Safety Plan
FTS	Flight Termination System
GLN-MAC	Gimbal-mounted LN-200 with Sandia Miniature Airborne Computer
GNC	Guidance, Navigation, Control
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSP	Ground Safety Plan
GUI	Graphic User Interface
I&T	Integration and Testing
IIP	Inertial Impact Point
IMU	Inertial Measurement Unit
ITAR	International Traffic in Arms Regulations
LIS	Lost in Space
LISS	Lockheed Intermediate Sun Sensor
LSRS	Launch Status Review System
LTM	Linear Thrust Module
MaNIACS	Magnetic NSROC Inertial Attitude Control System
MASS	Miniature Acquisition Sun Sensor
MCR	Mission Close-out Report
MFT	Multi-Function Timer
MIC	Mission Initiation Conference
MM	Mission Manager
MOI	Moment of Inertia
MRR	Mission Readiness Review

MSB	Most Significant Bit
MTF	Magnetic Test Facility
NIACS	NSROC Inertial Attitude Control System
NiCAD	Nickel Cadmium
NiMH	Nickel Metal Hydride
NOAA	National Oceanic and Atmospheric Administration
NSROC	NASA Sounding Rocket Operations Contract
NSRP	NASA Sounding Rockets Program
ORSA	Ogive Recovery System Assembly
PCD	Power Control Distribution
PCM	Pulse Code Modulation
PI	Principal Investigator
PIR	Pre-Integration Review
RDM	Requirements Definition Meeting
RHC	Right Hand Circular
RLG	Ring Laser Gyro
RMFT	Reprogrammable Multi-Function Timer
RMMO	Range and Mission Management Office
RMS	Root Mean Square
RNRZ	Randomized Non-Return to Zero
RSM	Range Safety Manual
SGI	Silicon Graphics
SLIT	Solar Likeness Indicating Transducer
SME	Significant Military Equipment
SOQPSK	Shaped Offset Quadrature Phase Shift Keying
SPARCS	Solar Pointing Attitude Rocket Control System
SRDP	Science Requirements Data Package
SPI	Serial Peripheral Interface
SPS	Separable Pneumatics System
SPS	Samples per Second
SRWG	Sounding Rocket Working Group
SSOPD	Sub-orbital and Special Orbital Projects Office
ST	Star Tracker
T&E	Test and Evaluation
TAA	Technical Assistance Agreement
TM	Telemetry
TMA	Trimethylaluminum
TTC	Telemetry, Tracking, Command
UMFT	USB Reprogrammable Multifunction Timer
USML	US Munitions List
VAB	Vehicle Assembly Building
VCO	Voltage-controlled oscillator
WAASP	Wallops Accelerometer & Attitude Sensor Package
WFF	Wallops Flight Facility
WSMR	White Sands Missile Range