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**Report of the SRWG Sub-committee on High Altitude Rockets to Increase Astrophysics and Solar Observing Time**

**Summary:**

The astrophysical and solar science that can be executed by sounding rocket payloads is limited by the available time above 150 - 250 kilometers. This restricts both the science goals that can be executed and the new technologies that can be implemented by sounding rocket payloads, thus decreasing the potential of the program for scientific advancement and innovation.

Use of the Black Brant XI and XII launch vehicles has great potential for impacting and extending the science achieved by the Sounding Rocket Program (SRP) by significantly increasing the available observing time above 250 km.

Science capabilities would be extended (1) by permitting execution of programs that would otherwise be background limited (faint sources) or (2) instrument limited (e.g. higher resolution spectroscopy, novel technologies) and hence unachievable, (3) by enabling access to regions of the southern celestial sky that are inaccessible from the northern hemisphere (e.g. Woomera Launch Facility), and (4) by providing time to observe an increased number of targets (pointings) on a single flight.

The SRWG requests that the SRPO study the following three options for launch of Black Brant XI, and XII vehicles to achieve the best balance between a rewarding and exciting scientific program that is capable of testing new ideas and technologies and yet remains cost-effective. Consideration should be given to the increase in observing time, additional sky coverage achievable, rocket dispersion, payload recovery costs, and infrastructure costs.

1. Launch of the Black Brant XI, and XII launch vehicles from WSMR
2. Launch with a water recovery of science payloads and sounding rocket motors
3. Launch from an alternate launch range (e.g Woomera) with payload recovery

**Increasing Observation Time for Astrophysics and Solar Missions**

The objectives of the sounding rockets over the past 50 years have been primarily:

1. Maintain a low-cost program with frequent launch opportunities for scientists in diverse science disciplines.
2. Improve payload sub-system performance, particularly where they offer important advantages to scientists, for example pointing accuracy and stability, flexible PCM data encoding, and higher downlink data rates.
3. Increase observation time in space, thereby widening the envelope of the scientific research and increasing the incentive for new instrument development.

This report urges the SRPO to address the capability of the SRP to enable cutting-edge science through an increase in the available sounding rocket observing time and hence access to space (item 3) in a cost-effective and timely manner (item 1).

For astrophysics and solar missions the preferred vehicle is the Black Brant IX (BB IX), which consists of a Black Brant V (BB V) rocket equipped with a Terrier Mk. 70 booster. Typically these missions launch from White Sands Missile Range (WSMR) primarily to enable payload recovery but also to take advantage of the low particle background at mission altitudes. While increased observing time can be realized using the BB X, XI and XII launch vehicles (**Table 1**) it usually comes at the cost of payload recovery. Payload recovery after a BB X, XI or XII launch implies either use of a large land range or recovery operations at sea. Water recovery of payloads launched from WFF with modest impact ranges has been performed, but the re-entry conditions and the greater impact ranges of the BB X, XI and XII will require payload technical developments and new demands upon sea recovery operations. The geophysics community takes advantage of the higher altitudes and flight times of the BB X, XI and XII vehicles knowing that payload recovery from the Poker Flat range will not be undertaken.

Astrophysics and solar payloads represent a significant investment in both time and funding. These payloads are usually re-flown or cannibalized for new payload designs. Abandoning payload recovery is a costly option of last resort.

**Table 1 The stage configuration of the BB IX, X, XI and XII vehicles.**

| Vehicle | First stage | Second stage | Third stage | Fourth stage |
|---|---|---|---|---|
| BB IX | Terrier Mk 70 | Black Brant V | | |
| BB X | Terrier Mk 12 | Black Brant V | Nihka | |
| BB XI | Talos | Taurus | Black Brant V | |
| BB XII | Talos | Taurus | Black Brant V | Nihka |

**Time gains:** The increase in observing time that can be expected from use of the BB X, XI and XII are summarized in **Table 2.** Times above two fiducial altitudes are provided: an altitude of 150 km, which satisfies many astrophysical and solar observations, and 250 km, a figure of merit for astrophysical observations at infrared wavelengths. The greatest gains can be achieved for payloads (e.g. near-infrared) where OH and other high-altitude contaminants are a concern. Using **Table 2**, we estimate that for launches from WFF (i.e. near sea-level) the gains in time above 250 km relative to the BB IX are 164, 114 and 75 percent for the BB XII, XI and X respectively. The percentage gains in time over 150 km are 85, 62 and 41 percent respectively.

**Table 2 The apogee altitude, impact range and times above 150 and 250 km for a 1000 lb payload launched by the BB IX, X, XI and XII from WFF, and by the BB IX launched from WSMR : Q.E. = 85˚**

| Range | Vehicle | Apogee km | Range km | Time above 150 km sec | Time above 250 km sec |
|---|---|---|---|---|---|
| WFF | BB IX | 294 | 169 | 321 | 194 |
| WSMR | BB IX | 312 | 122 | 379 | 232 |
| WFF | BB X | 377 | 290 | 454 | 340 |
| WFF | BB XI | 438 | 272 | 521 | 416 |
| WFF | BB XII | 528 | 433 | 595 | 513 |

**WSMR constraints:** The size and geometry of WSMR has deterred the launch of science payloads using the BB X, XI and XII vehicles. **Table 2** summarizes the apogee altitude and impact range of the BB IX launched from WSMR, and of the BB IX, X, XI and XII launched from WFF. The small impact dispersion of the BB IX (**Table 3**) is achieved with the help of the S-19 boost phase guidance system. The 1-sigma impact point dispersions for the BB XI and BB XII (**Table 3**) are a function of the apogee altitude. The difficulty of launching the BB X, XI and XII from WSMR is evident when the impact ranges shown in **Table 2** are combined with the estimated 1-sigma dispersions (**Table 3**) and compared against the physical dimensions of the range (**Table 4**). If the gains in observing time promised by the BB X, XI and XII are to be realized, then either a larger land range must be sought, a low-dispersion alternate to the Nihka stage found, a thrust termination system developed, or sea recovery undertaken and a cost-benefit of these alternatives assessed.

**Table 3 Approximate 1-sigma impact dispersions for the BB IX, XI and XII**

| Vehicle | Apogee km | Range km | EW 1-sigma Dispersion | NS 1-sigma Dispersion |
|---|---|---|---|---|
| BB IX | 312 | 122 | 8 | 8 |
| BB XI | | | 40 | 60 |
| BB XII | | | 120 | 130 |

**Table 4 Physical size of potential launch ranges for the BB IX, XI and XII vehicles.**

| Range | EW Size [km] | NS Size [km] | Recovery |
|---|---|---|---|
| WFF | | | water |
| WSMR | 60 | 160 | land |
| WSMR + North Extension | 60 | 215 | land |
| Roi Namur (RTS) | | | water |
| Woomera (WTF) | 600 | 220 | land |

**Costs:** Excepting the option for an alternate or modification to the Nihka stage, it should be emphasized that **no new vehicle development is needed.** The use of refurbished military motors has been successful in holding down the costs of the BB X, BB XI or XII vehicles.

The increased observing time (**Table 2**) versus cost (**Table 5**) was evaluated for these vehicles. The dominant costs are those the BB V and the Nihka motor. Although both the BB X and the BB XII use the Nihka motor, resulting in rocket motor costs that are the same to within 4%, the BB XII is expected to attain much greater gains in observing time (51% for time above 250 km ) relative

the BB X (**Table 2**). The BB X does not appear to be a cost-effective option for payloads in the 1000 lb class.

The BB XII offers the greatest potential gain in observing time. However, it uses the more costly and higher dispersion inducing Nihka motor, providing strong incentives to replacing, modifying, or reducing the price of the Nihka motor. The BB XI does not use a Nihka motor and is an attractive and cost effective option for programs whose science goals can be achieved at the lower fiducial altitude of 150 km.

**Table 5 Cost of Rocket Motors for the Black Brant IX, X, XI and XII**

| Vehicle | Terrier Mk 12 with fins K$ | Terrier Mk 70 with fins K$ | Talos with fins K$ | Taurus with fins K$ | BB V + igniter + Igniter housing K$ | Nihka + igniter + igniter housing K$ | Total K$ |
|---|---|---|---|---|---|---|---|
| BB IX | | 15 | | | 546 | | 561 |
| BB X | 15 | | | | 546 | 274 | 835 |
| BB XI | | | 29 | 17 | 546 | | 592 |
| BB XII | | | 29 | 17 | 546 | 274 | 866 |

**Alternate ranges:** SRPO has experience in launching sounding rockets from two southern ranges, Roi Namur in the Marshall Islands (Reagan Test Site (RTS): US Army) and the Woomera Test Facility (WTF) in Australia**,** which are attractive candidates for launch of the BB IX, X, XI and XII vehicles. *The WTF can accommodate the impact range and dispersion of these vehicles, satisfy the requirement for low particle background at sounding rocket altitudes, allow payload recovery, and provide access to the region around the South Celestial Pole which is inaccessible from WSMR, a factor important to astrophysicists.*

Costs associated with launch from an alternate site will depend upon the on-site capability and availability of technical and operations infrastructure.

Launch from Roi Namur would require water recovery. Payload modifications and the development of techniques for water recovery at impact ranges of 300-500 km would be necessary. Experience (Cruddace) at the RTS indicates that operations have decreased in number in recent years. Therefore, a careful study is needed to assess the technical infrastructure available for launch of the BB IX, XI and XII series of vehicles from the RTS as well as the high altitude particle background.

The WTF operates a launch range of about 127,000 sq. km, measuring ~ 600 × 220 km (**Table 4**), as shown in the appended map. Comparison of the 1-sigma impact dispersions (**Table 3**) with range dimensions indicates that launches of the BB XI and the BB XII and payload recovery should be feasible. Contrary to experience with the RTS, operations at the WTF are increasing. As of July, over 100 trials had taken place in 2009 (private communication: Cruddace). The growing technical infrastructure available at the range, the international scope of WTF operations, and the

invitation to extend and negotiate the use of range facilities for new users are described in the attached document. Use of existing, on-site, technical infrastructure and operations, such as the SRPO uses U.S. Army facilities for tracking, range control and recovery at WSMR, would significantly reduce the cost of an ongoing NASA sounding rocket program at WTF.

The SRWG requests that the SRPO study the installation of infrastructure capable of launching the BB XI and XII vehicles, for astrophysics and solar physics sounding rocket missions, with the following objectives:

1. The range should be capable of launching the BB XI and XII vehicles, with a second range (e.g. WSMR) capable of launching solely the BBXI studied as a non-exclusive option.

2. The range should give access to the region of sky around the south celestial pole that is inaccessible from WSMR.

3. The payloads should be recoverable.

4. Determine to what extent NASA could use the technical infrastructure at the range for sounding rocket operations. *Is it possible, using these facilities plus equipment installed permanently at the range by WFF, to reduce the cost of sounding rocket operations to the point where missions could be flown there on a regular basis?*

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