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VIA ELECTRONIC DELIVERY

June 18th, 2017

**TO: Experimental Licensing Service (ELS) / Office of Engineering and Technology (OET)
Federal Communications Commission (FCC)
445 12th Street, SW
Washington, DC 20554**

RE: Launch Update for Arkyd 6B satellite experimental authorization 0025-EX-PL-2016

To Whom It May Concern:

This memorandum is to update the FCC on the launch status of the Arkyd 6B satellite built and operated by Planetary Resources Development Corporation (PRDC). Because several launch delays, the launch manifest for the satellite was changed to a new launch vehicle and launch date. Launch of the satellite is now as follows:

- Launch Date: October 2017
- Launch Vehicle: PSLV
- Launch Site: Satish Dhawan Space Centre, India
- Orbit: 550 - 580 km circular sun-synchronous orbit (SSO), 10:30 LTAN

As part of the documentation of this change, PRDC has attached the following updated document to this memorandum:

- Arkyd 6B Orbital Debris Assessment Report, Revision A, dated June 14th, 2017

If you have any questions concerning the foregoing, please do not hesitate to contact me directly.

Respectfully submitted,

Chris Voorhees
Chief Engineer
Planetary Resources Development Corporation
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ARKYD 6B SPACECRAFT

Orbital Debris Assessment Report (ODAR)

REVISION A

Date: 06/14/2017

Chris Voorhees, Planetary Resources Development Corporation
Vice President of Spacecraft Development

DOCUMENT CHANGE LOG:

1. Initial Release: 01/08/2016
2. Revision A: 06/14/2017
   Launch vehicle, launch date, and orbit change

ARKYD 6 ORBITAL DEBRIS ASSESSMENT REPORT (ODAR)

This document contains Planetary Resources Development Corporation's (PRDC's) orbital debris assessment report (ODAR) for the Arkyd 6 (A6B) spacecraft. The format for this report complies with that which is recommended in NASA-STD-8719.14, Appendix A.1 and includes Sections 2 – 8 as applicable to the A6B vehicle. Table 1 includes a summary of the results presented in the following sections.

Table 1: ODAR Compliance Table

ODAR Requirement for Arkyd 6 Spacecraft	Compliant or N/A	Not Compliant	Incomplete	Notes
4.3-1.a	X			see Section 3
4.3-1.b	X			see Section 3
4.3-2	X			see Section 3
4.4-1	X			see Section 4
4.4-2	X			see Section 4
4.4-3	X			see Section 4
4.4-4	X			see Section 4
4.5-1	X			see Section 5
4.5-2	X			See Section 5
4.6-1(a)	X			see Section 6
4.6-2	X			see Section 6
4.6-3	X			see Section 6
4.6-4	X			see Section 6
4.7-1	X			see Section 7
4.8-1	X			see Section 8

ODAR SECTION 1: PROGRAM MANAGEMENT AND MISSION OVERVIEW

Project Manager: Chris Voorhees

Foreign Government / Space Agency Participation: None

Schedule of Upcoming Mission Milestones:

- Delta Mission Readiness Review: June 28th, 2017
- Launch: October 2017

Mission Overview:

The A6B spacecraft will nominally be launched onboard a PSLV launch vehicle in October 2017 as a secondary payload and released into a circular, sun-synchronous orbit of 550-580 km altitude. The A6B mission will demonstrate several new PRDC-developed hardware and software technologies in a relevant space environment over its nominal 24-month mission lifetime. A6B is an identical spacecraft to PRDC's Arkyd 6A (A6) spacecraft, currently scheduled for launch in December 2017 and operated under FCC experimental authorization 0850-EX-PL-2014.

ODAR Summary:

1. No orbital debris is released as a result of normal operations
2. There are no credible scenarios for spacecraft breakup
3. Collision probability is compliant with NASA ODAR Requirement 4.5-1 and 4.5-2 (as calculated by DAS v2.0.2)
4. Estimated nominal decay lifetime due to atmospheric drag is significantly less than 25 years (around 8 years as calculated by DAS v2.0.2) and is therefore compliant with NASA ODAR Requirement 4.6
5. Reentry debris casualty risk is compliant with NASA ODAR 4.7-1 (as calculated by DAS 2.0.2)

Launch Vehicle and Launch Site: PSLV; Satish Dhawan Space Centre (SDSC), India

Proposed Launch Date: October 2017

Mission Duration:

1. Primary nominal operations: 24 months after deployment
2. Post-operations orbital lifetime: ~8 years (2026)

Launch and Deployment Profile:

The spacecraft will nominally be launched onboard a PSLV launch vehicle in October 2017. A6B will be integrated to the launch vehicle as a secondary payload by Spaceflight, Inc. of Seattle, Washington. Arkyd 6B anticipates operations to commence no earlier than thirty (30) minutes after launch and on-orbit deployment of the launch vehicle's secondary payload complement. Figure 1 summarizes the launch and deployment details for the A6B vehicle.

Target Launch Date	October 2017
Launch Vehicle	PSLV
Secondary Payload Config.	Various
Secondary Payload Aggregator	Spaceflight, Inc.
A6B Launch Configuration	ISIPOD 6U CubeSat, Innovative Solutions in Space (ISIS)
Perigee Altitude	550 – 580 km
Apogee Altitude	550 – 580 km
Local Time of Asc. Node	10:30 +15m / -30m
Inclination	98.0 +/- 1 degrees

Figure 1: A6B Launch and Deployment Information Summary

ODAR SECTION 2: SPACECRAFT DESCRIPTION

Section 4.0 of this document provides a general summary of the spacecraft description, including hardware complement, mass, and volume.

Total satellite mass at launch, including all propellants and fluids: ~ 9.3 kg

Dry mass of satellite at launch, excluding solid rocket motor propellants: ~ 9.3 kg

Description of all propulsion systems: None

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes:

A6B contains a small (<5.9 cc) volume of helium, pressurized to 1.51 MPa (220 psi), as part of an onboard instrument. The same instrument component also contains a vacuum volume of around 20 cc

Fluids in pressurized batteries: None. A6B uses unpressurized COTS lithium-polymer battery cells

Description of attitude control system and indication of normal attitude of spacecraft with respect to the velocity vector:

A6B has utilizes a system of three (3) coil magnetorquers and three (4) reaction wheel assemblies to provide redundant means of spacecraft attitude control. Nominally, the spacecraft will fly with its solar arrays in a sun-point configuration.

Description of any range safety or other pyrotechnic devices: None

Description of the electrical generation and storage system:

A battery assembly of ten (10) COTS Lithium-Polymer battery cells is charged at the time of vehicle delivery for launch integration. This 96 W-hr battery provides electrical energy to spacecraft subsystems during the completion of the primary mission. Solar cells located on the primary structure and the two (2) deployable array elements recharge the battery assembly while on-orbit. Onboard power management and distribution electronics controls the state of charge of the battery and distribution of power to other spacecraft elements, while a protection circuit at the battery cells prevents inappropriate cell charge and discharge events.

Identification of any other sources of stored energy not noted above: None

Identification of any radioactive materials on board: None

ODAR SECTION 3: ASSESSMENT OF SPACECRAFT DEBRIS - NOMINAL OPERATIONS

Identification of any object > 1 mm expected to be released from spacecraft after launch: None

Rationale / necessity for release of each object: N/A

Time of release of each object, relative to launch time: N/A

Release velocity of each object with respect to spacecraft: N/A

Expected orbital parameters of each object after release: N/A

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit: N/A

Assessment of spacecraft compliance with ODAR Requirements 4.3-1 and 4.3-2 (per DAS v2.0.2)

- 4.3-1, Mission Related Debris Passing Through LEO: **COMPLIANT**
- 4.3-2, Mission Related Debris Passing Near GEO: **COMPLIANT**

ODAR SECTION 4: ASSESSMENT OF SPACECRAFT INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSION

Potential causes of spacecraft breakup during deployment and mission operations:

There are no credible causes of spacecraft breakup during nominal deployment and mission operations

Summary of failure modes and effects analyses of all credible failure modes that may lead to an accidental explosion:

The spacecraft's energy management system uses COTS Lithium-Polymer battery cells. In the unlikely event of a failure of the cell's protection circuit, a short circuit could occur, resulting in potential overheating and a remote possibility of cell material venting. PRDC's internal FMEA indicates (including below) indicates the multiple failures required for a battery system failure to initiate an unexpected, accidental vehicle explosion.

The vehicle's configuration also includes two (2) simple spring-deployed solar array deployments and a single spring-deployed context camera deployment boom, all of which are restrained by a burn-wire device with redundant launch load restraint elements. The probability of an unexpected detachment before, during, and after deployment is therefore considered negligible.

The spacecraft instrument's pressurized helium volume has a risk of uncontrolled venting due to a structural fault. The instrument carries a total helium mass of 130 mg. However, the total volume and stored energy is very small (5.9 cc and 8.9 J, respectively), so the probability of this event contributing to the explosion of the vehicle is negligible.

Detailed plan for any designed spacecraft breakup: None planned

List of components that shall be passivated at End of Mission (EOM):

No component passivation is planned. The spacecraft's six Lithium-Polymer cells will not be passivated at the end of primary mission due to the low risk and negligible impact of accidental explosion. The maximum total energy stored in each cell is ~ 35 kJ.

Rationale for all items that are required to be passivated but cannot due to their design:

The design of A6B includes onboard battery management and overcharge protection for each battery cell, making the risk of a cell failure while on orbit very low. However, in the event that a cell failure does result in material venting, the cell's small size and low overall storage energy ensures that debris from the event will remained contained by the spacecraft's aluminum primary structure.

Assessment of spacecraft compliance with ODAR Requirements 4.4-1 through 4.4-4:

- 4.4-1: Limited the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon
  - Required Probability: 0.001 – **COMPLIANT**
  - Supporting Rationale and FMEA
    - The following failure could theoretically result in a battery explosion with a remote possibility of orbital debris generation. However, in the event that a cell failure does result in material venting, the cell's small size and low overall storage energy ensures that debris from the event will remained contained by the spacecraft's aluminum primary structure. The probability of multiple independent failures leading to orbital debris generation in the event of a cell failure is considered to be much less than 0.1%
    - Failure Mode 1: Internal cell short circuit
      - Mitigations: Qualification and acceptance dynamic, thermal, and vacuum testing, followed by qualification charge / discharge cycling.
    - Failure Mode 2: Increase in cell temperature resulting in venting
      - Mitigation: Cell screening includes an overtest of expected in-flight charge / discharge characteristics to evaluate the possibility of unexpected intra-cell heating and subsequent failures. No failures were seen during these overtests. This test was also completed at the battery assembly level to ensure no integration issues were present.
    - Failure Mode 3: Excessive discharge rate or short circuit due to external device failure
      - Mitigations: 1) qualification testing of short-circuit protection of each battery cell; 2) design of battery assembly to ensure that there is no possibility of contact with other conductive paths in proximity to the battery; and 3) confirmation of no other credible mechanical failure near the battery through a full, successful environmental test program, including launch dynamics.
    - Failure Mode 4: Battery cell vent path failure
      - Mitigation: Failure mode is mitigated by the design of the battery assembly, which includes a vent path for each cell
    - Failure Mode 5: Crushing
      - Mitigation: Failure mode is mitigated by the design of the battery assembly housing. Multiple, catastrophic internal mechanical failures must occur for an individual battery cell to be crushed.
    - Failure Mode 6: Excess battery cell temperature due to orbital environment

            - Mitigation: Failure mode is mitigated by spacecraft thermal design and subsequent ground thermal vacuum testing of non-operational and operational thermal environments to ensure spacecraft design compatibility. Specifically, the battery assembly is subjected to maximum charge and discharge events while under "hot-case" thermal environment conditions to ensure that no deleterious effects are indicated.
        - Failure Mode 7: Uncontrolled venting of instrument pressurized helium volume
            - Mitigation: Qualification and unit acceptance dynamic, thermal, and vacuum testing, followed by operational cycling over expected temperature range.

- Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon:
    - Compliance Statement: The design of A6B includes onboard battery management and overcharge protection for each battery cell, making the risk of a cell failure while on orbit very low. However, in the event that a cell failure does result in material venting, the cell's small size and low overall storage energy ensures that debris from the event will remained contained by the spacecraft's aluminum primary structure. This is also the case for the smaller instrument pressurized helium volume - **COMPLIANT**
- Requirement 4.4-3: Limiting the long-term risk to other space systems from planned breakups:
    - Compliance Statement: **Not applicable**; there are no planned spacecraft breakups.
- Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups:
    - Compliance Statement: **Not applicable**; there are no planned spacecraft breakups.

ODAR SECTION 5: ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS

Assessment of spacecraft compliance with ODAR Requirements 4.5-1 and 4.5-2:

- 4.5-1: Limiting debris generated by collisions with large objects when operating in Earth orbit (per DAS v2.0.2):
  - **COMPLIANT** per DAS v2.0.2; Collision Probability = 0.000002
- 4.5-2: Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:
  - Compliance Statement: **Not applicable**; The spacecraft is planned orbital disposal by atmospheric entry, and does not require a specific spacecraft orientation and drag state to meet the disposal requirements outlined in ODAR Section 6. Therefore, no element or component of the spacecraft system is required to complete post-mission operations.

ODAR SECTION 6: ASSESSMENT OF SPACECRAFT POST-MISSION DISPOSAL PLANS AND PROCEDURES

Description of spacecraft disposal option selected:

Per NASA-STD 8719.14, the A6B spacecraft will be disposed naturally through atmospheric entry. Due to the vehicle's low initial orbit, it is expected to naturally de-orbit on its own well within the time limit specified in ODAR Requirement 4.6-1(a).

Plan for any spacecraft maneuvers required to accomplish post-mission disposal

No special maneuvers or operations are required to accomplish post-mission disposal. The spacecraft will naturally de-orbit well within the requirements of NASA-STD 8719.14 without any special action.

Calculation of area-to-mass ratio after post-mission disposal

- Spacecraft mass: ~ 9.3 kg
- Cross-sectional area: 0.116 m^2 (average assuming uncontrolled tumble)
- Area-to-mass ratio: 0.012 m^2 / kg (average assuming uncontrolled tumble)

Assessment of spacecraft compliance with ODAR Requirements 4.6-1 through 4.6-4

- 4.6-1(a): Disposal for space structures in or passing through LEO:
  - **COMPLIANT** per DAS v2.0.2; Passed with expected de-orbit in 2026, with an ~8-year on-orbit lifetime

- 4.6-2: Disposal for space structure near GEO
  - **Not applicable**
- 4.6-3: Disposal for space structures between LEO and GEO
  - **Not applicable**
- 4.6-4 Reliability of post-mission disposal operations
  - The spacecraft's maximum drag orientation is also its aerodynamically stable state. Therefore, even given a fault scenario in which spacecraft orientation control is lost, the spacecraft will de-orbit at or before the timeframe outlined in 4.6-1(a), which assumes a lower, average area-to-mass mass ratio assuming an uncontrolled tumble instead of the maximum drag orientation. - **COMPLIANT**

ODAR SECTION 7: ASSESSMENT OF SPACECRAFT REENTRY HAZARDS

Assessment of spacecraft compliance with ODAR Requirement 4.7-1:

- 4.7-1(a): Limit the risk of human casualty from surviving debris for an uncontrolled reentry to no greater than 0.0001 (1:10,000)
  - **COMPLIANT** per DAS v2.0.2; No risk of human casualty for surviving debris
- 4.7-1(b): **Not applicable**; relevant only to controlled reentry
- 4.7-1(c): **Not applicable**; relevant only to controlled reentry

ODAR SECTION 8: ASSESSMENT FOR TETHER MISSIONS

This ODAR section (Reqt. 4.8-1) is **not applicable**. There are no tethers utilized onboard the A6B spacecraft.

ARKYD 6 DAS v2.0.2 OUTPUT FILE

```
04 17 2017; 13:48:36PM        DAS Application Started
04 17 2017; 13:48:37PM        Opened Project C:\Program Files (x86)\NASA\DAS 
2.0\sunsynch_580km\
04 17 2017; 13:59:31PM        Mission Editor Changes Applied
04 17 2017; 14:00:30PM        Mission Editor Changes Applied
04 17 2017; 14:00:47PM        Processing Requirement 4.3-1:        Return Status :  Not Run

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-1 ===============
04 17 2017; 14:00:50PM        Processing Requirement 4.3-2: Return Status : Passed

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No Project Data Available
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=============== End of Requirement 4.3-2 ===============
04 17 2017; 14:00:52PM        Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
04 17 2017; 14:01:00PM        Processing Requirement 4.5-1:        Return Status :  Passed

==============
```

Run Data
==============

INPUT

Space Structure Name = A6
Space Structure Type = Payload
Perigee Altitude = 580.000000 (km)
Apogee Altitude = 580.000000 (km)
Inclination = 97.710000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.012000 (m^2/kg)
Start Year = 2017.000000 (yr)
Initial Mass = 9.300000 (kg)
Final Mass = 9.300000 (kg)
Duration = 2.000000 (yr)
Station-Kept = False
Abandoned = True
PMD Perigee Altitude = -1.000000 (km)
PMD Apogee Altitude = -1.000000 (km)
PMD Inclination = 0.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Collision Probability = 0.000002
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==============

=============== End of Requirement 4.5-1 ===============
04 17 2017; 14:01:05PM Requirement 4.5-2: Compliant
04 17 2017; 14:01:07PM Processing Requirement 4.6 Return Status : Passed

==============
Project Data
==============

INPUT

Space Structure Name = A6
Space Structure Type = Payload

Perigee Altitude = 580.000000 (km)
Apogee Altitude = 580.000000 (km)
Inclination = 97.710000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.012000 (m^2/kg)
Start Year = 2017.000000 (yr)
Initial Mass = 9.300000 (kg)
Final Mass = 9.300000 (kg)
Duration = 2.000000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = 578.218536 (km)
PMD Apogee Altitude = 578.218536 (km)
PMD Inclination = 97.744392 (deg)
PMD RAAN = 359.486818 (deg)
PMD Argument of Perigee = 11.886683 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Suggested Perigee Altitude = 578.218536 (km)
Suggested Apogee Altitude = 578.218536 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2026 (yr)
Requirement = 61
Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
04 17 2017; 14:02:08PM *********Processing Requirement 4.7-1
Return Status : Passed

***********INPUT****
Item Number = 1

name = A6
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 9.300000
Thermal Mass = 9.300000
Diameter/Width = 0.200000
Length = 0.300000
Height = 0.100000

name = A6
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 9.300000
Thermal Mass = 9.300000
Diameter/Width = 0.200000
Length = 0.300000
Height = 0.100000

*************OUTPUT****
Item Number = 1

name = A6
Demise Altitude = 77.999699
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = A6
Demise Altitude = 57.132354
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

============== End of Requirement 4.7-1 ==============
04 17 2017; 14:02:14PM Project Data Saved To File