AKASH SYSTEMS

**July 18, 2018**

# Exhibit 6: Akash MCNAIR Orbital Debris Assessment Report (ODAR)

## 1. Scope

This report summarizes the analyses performed to assess orbital debris for Akash's MCNAIR satellite and its compliance with requirements established by the NASA Orbital Debris Program Office (OPDO). This report does not cover potential debris from the launch vehicle.

The analysis uses Debris Assessment Software provided by the NASA OPDO and follows the requirement structure of the Process for Limiting Orbital Debris, NASA-STD 8719.14A. The MCNAIR analysis was performed using version DAS 2.1.1 provided by the OPDO at NASA's Johnson Space Center (JSC). This analysis complies with the methodology described in Section 1.1.3 of NS 8719.14A: *"1.1.3 This document, along with the associated current version of Debris Assessment Software (DAS) or the higher fidelity Object Reentry Survival Analysis Tool (ORSAT), provided by the NASA Orbital Debris Program Office (NASA ODPO) located at Johnson Space Center (JSC), shall be used by the program or project manager as the primary reference in conducting orbital debris assessments (Requirement 56244)."*

## 2. Mission Design

### 2.1 Mission Description

A complete Mission Description is provided in Exhibit 1 of Akash's MCNAIR STA Application.

It is important to note that Akash has no plans to intentionally release debris during nominal satellite operations, and that MCNAIR has been designed without propulsion and, therefore, no pressure vessels are on-board. Before launch, Akash will designate a point of contact for receiving JSpOC conjunction assessments, and plans for collision avoidance activities will be developed if necessary. Additionally, MCNAIR does have the ability, upon receipt of a ground command, to orient itself at a given altitude in order to vary its cross-sectional area in the vector of motion.

In terms of foreign government or space agency participation, The Akash satellite, MCNAIR, has not received support of any form from any foreign government or space agency.

### 2.2 Spacecraft Description

MCNAIR is a 3-axis controlled, 12U CubeSat designed for use in a low earth orbit (LEO) with two deployed, non-articulating solar arrays. There is also a deployed Ka-band antenna and an S-band patch antenna. The total spacecraft mass (and dry mass) is 19.9 kg. The dimensions of the 12U spacecraft are 23.9 cm x 22.9 cm x 36.6 cm in the stowed configuration. This does not include the stowed Ka-band parabolic antenna which is fixed to the nadir facing wall, and measures 16.6 cm in height and 10.4 cm in diameter. When fully deployed, the Ka-

band antenna extends approximately 34 cm in height and 51 cm in diameter, the two deployed solar arrays have a dimension of 30 cm x 40 cm each.

The 3-axis inertial pointing system contains three reaction wheel assemblies, three torque rods, two miniaturized star trackers, and a processor board. The MCNAIR bus battery is capable of 100 Watt-hr, and has charge control, power distribution and fault protection. The payload battery consists of 24 cells, providing 300 Watt-hr at 28V.

All sensors on MCNAIR are passive and there are no lasers, propellants, radioactive, pyrotechnic devices, pressure vessels, or other hazardous materials on board the spacecraft.

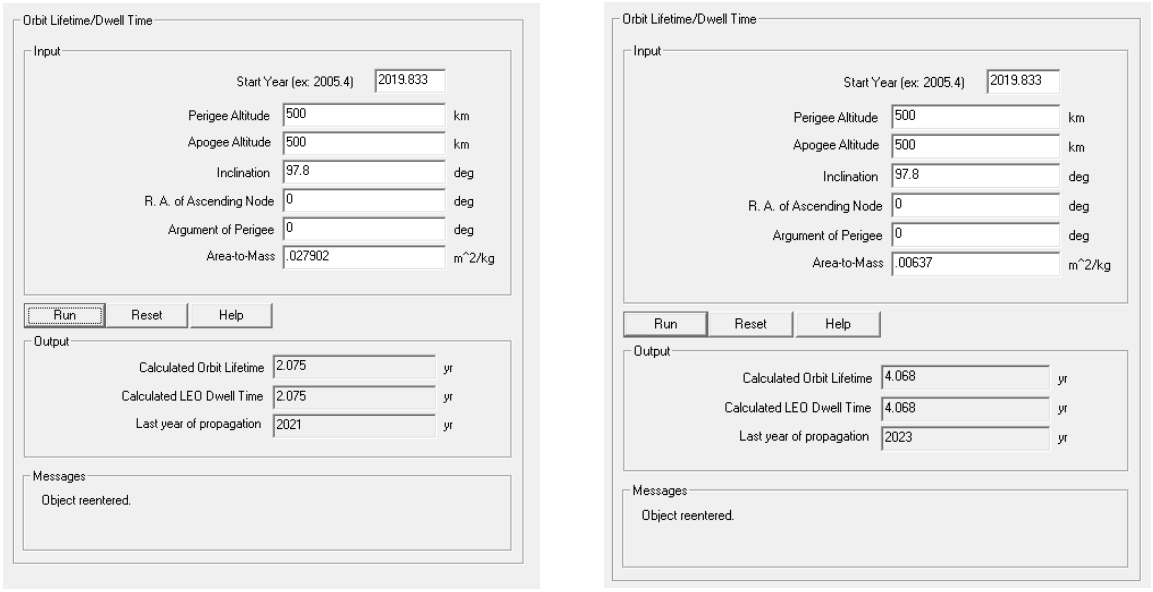
## 3. Orbit Lifetime

NASA requires the disposal of spacecraft through one of three methods; 1) atmospheric reentry within 25 years of Mission completion or 30 years from launch, maneuver the spacecraft for a controlled reentry, 2) maneuver the spacecraft into a storage orbit, or 3) direct retrieval. MCNAIR will meet NS 8719.14 through atmospheric reentry within 25 years mission completion *[(Requirement 4.6-1) - Disposal for space structures passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: a. Atmospheric reentry option: (1) Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or…].*

For the orbital lifetime analysis, an initial orbit of 500 x 500 km altitude and 97.8 degrees inclination was input into the DAS software. The software was also used to calculate the cross sectional area of the spacecraft for random tumbling and a detailed mass budget was used to accurately estimate the fully integrated spacecraft mass.

For a fully deployed configuration, a 5552.48 $cm^2$ cross sectional area was estimated using the "Calculate the Cross Sectional Area" in the DAS Science and Engineering toolbox. Since the spacecraft mass is 19.9 kg, the area-to-mass ratio is 0.0279 $m^2/kg$ for MCNAIR (in the fully deployed configuration). In this configuration, re-entry would occur after 2.075 years.

While it is highly unlikely for both the solar arrays and the Ka-band antenna to not deploy, analysis was conducted for a fully stowed configuration as well. For a fully stowed configuration, the area-to-mass ratio is 0.00637 $m^2/kg$, and the spacecraft would reenter in 4.068 years. The inputs to the calculation and the orbit history for a (a) fully deployed and (b) fully stowed configuration are shown in Figure 1 (a,b).




(a) Fully Deployed (b) Fully Stowed

*Figure 1(a,b). Inputs and Outputs to the Orbital Lifetime / Dwell Time Calculation for a (a) fully deployed configuration and (b) fully stowed configuration*

Therefore, the worst-case orbit dwell time for a 500 km sun-synchronous orbit is 4.068 years, meeting requirement 8719.14 through atmospheric reentry within 25 years of mission completion or 30 years from launch. However, it is important to note that the plan is to re-enter in the fully deployed configuration, and therefore re-enter within 2.075 years.

Additionally, sun synchronous orbits at 400 km and 600 km, were also run in both the fully deployed and fully stowed configuration. Successfully reentry was found to occur for both of these orbits, and in both of the configurations. The worst-case scenario occurs at 600 km fully stowed, which has an orbit lifetime of 23.584 years.

## 4. Orbital Debris Requirements

Requirements associated with the risk of human casualty from reentering space hardware are contained in NS 8719.14A, requirement 4.7-1: *[Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 Joules: a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000)…]*

All analyses contained in the DAS 2.1.1 Requirements Assessment tools were successfully performed with the exception of collision hazards from space tethers. There are no tethers on MCNAIR.

### 4.1 Model Construction

In order to calculate the risk of human casualty, the arrangement of each space structure element is defined to assess its reentry survival potential. Based on empirical and theoretical

values, the outermost structure (i.e. the "parent" object) is assumed to break apart at an altitude of 78 km. The first level of "child" objects is exposed at this point. The objects are then subjected to the various forces of the reentry model. If a child object is destroyed ("demises") due to the reentry forces, it does not affect the final casualty area calculation. If a child object contains further levels of children, those children are exposed at the same point at which their immediate parent is exposed.

MCNAIR components and their physical properties were inserted into the object tree with sub-items (child objects) nested to match the mechanical design of the system. The root level (0th) object for the object tree is the MCNAIR structure. The first level of child objects contains the thermal structures, avionics box, solar arrays, batteries, the Akash transmitter and the associated antenna.

## 4.2 Orbital Debris Analysis Results

A summary of the orbital debris analyses results is shown in Figure 2. MCNAIR is compliant with NS 8719.14A – Process for Limiting Orbital Debris. There are no tethers on MCNAIR.

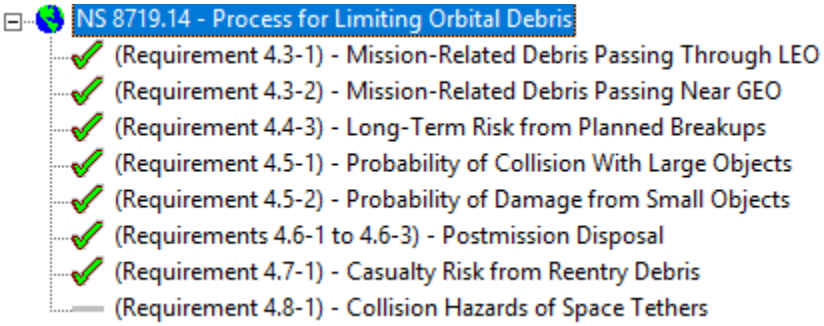



*Figure 2. MCNAIR Compliance with Orbital Debris Requirements*

Numerical results for the risk of human casualty for the total mission is shown in Figure 3. The risk of human casualty is "1:49900" and the total casualty area is 1.79m$^2$. The nonzero casualty area is produced by the solar panels alone. The spacecraft and all of its internal components oblate with a risk to human casualty that is compliant with Requirement 4.7-1, which states that *"For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000)"*.

Output

| Object Name | Compliance Status | Risk of Human Casualty | SubComponent Object | Demise Altitude (km) | Total Debris Casualty Area ... | Kinetic Energy (J) |
|---|---|---|---|---|---|---|
| Akash | Compliant | 1:49900 | | | 1.79 | |
| | | | X Radiator Pa... | 73.7 | 0.00 | 0 |
| | | | Y Radiator Pa... | 73.7 | 0.00 | 0 |
| | | | Avionics Box | 54.5 | 0.00 | 0 |
| | | | Solar Array Pa... | 0.0 | 1.79 | 306 |
| | | | Akash Transm... | 60.8 | 0.00 | 0 |

Messages

Akash Requirement 4.7-1 Compliant

*Figure 3. MCNAIR Risk of Human Casualty*

## 5. Summary

An orbital debris analysis found the MCNAIR 12U CubeSat mission to be compliant with the applicable requirements for spacecraft disposal and risk to human casualty contained in NASA STD 8719.14A. The analysis uses Debris Assessment Software provided by the NASA ODPO and follows the requirement structure of the Process for Limiting Orbital Debris, NASA-STD 8719.14A. On October 1, 2019, MCNAIR will be launched into a 500 km altitude, 97.8 degree inclination orbit and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 4.068 years (fully stowed configuration) and 2.075 years (fully deployed configuration) and is compliant with the requirement to reenter within 25 years after mission completion or 30 years after launch.

The inputs to the DAS object tree (spacecraft model) were nested according to the users guide to provide a realistic reentry model and used the standard materials database provided in the application.

MCNAIR meets all applicable requirements for the process of limiting orbital debris.

## 6. Appendix

```
**INPUT**

      Start Year = 2019.833000 (yr)
      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 97.800000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Area-To-Mass Ratio = 0.027902 (m^2/kg)

**OUTPUT**
```

Orbital Lifetime from Startyr = 2.075291 (yr)
Time Spent in LEO during Lifetime = 2.075291 (yr)
Last year of Propagation = 2021 (yr)

**INPUT**

Start Year = 2019.833000 (yr)
Perigee Altitude = 500.000000 (km)
Apogee Altitude = 500.000000 (km)
Inclination = 97.800000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.006370 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 4.068446 (yr)
Time Spent in LEO during Lifetime = 4.068446 (yr)
Last year of Propagation = 2023 (yr)

---

07 12 2018; 16:37:00PM
Processing Requirement 4.3-2: Return Status: Passed
========== End of Requirement 4.3-2 ==========

07 12 2018; 16:37:03PM Requirement 4.4-3: Compliant
========== End of Requirement 4.4-3 ==========

07 12 2018; 16:44:46PM Processing Requirement 4.5-1: Return Status: Passed
==========
Run Data
==========

**INPUT**

Space Structure Name = Akash
Space Structure Type = Payload
Perigee Altitude = 500.000000 (km)
Apogee Altitude = 500.000000 (km)
Inclination = 97.800000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.027900 (m^2/kg)
Start Year = 2019.833000 (yr)
Initial Mass = 19.900000 (kg)
Final Mass = 19.900000 (kg)

AKASH SYSTEMS

```
      Duration = 0.500000 (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 ===============

07 12 2018; 16:45:51PM
Processing Requirement 4.6   Return Status:  Passed

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

**INPUT**

      Space Structure Name = Akash
      Space Structure Type = Payload

      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 97.800000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.027900 (m^2/kg)
      Start Year = 2019.833000 (yr)
      Initial Mass = 19.900000 (kg)
      Final Mass = 19.900000 (kg)
      Duration = 0.500000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 486.384674 (km)
      PMD Apogee Altitude = 510.419690 (km)
      PMD Inclination = 97.783203 (deg)
      PMD RAAN = 188.805122 (deg)
      PMD Argument of Perigee = 52.099452 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**
```

```
      Suggested Perigee Altitude = 486.384674 (km)
      Suggested Apogee Altitude = 510.419690 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

      Released Year = 2021 (yr)
      Requirement = 61
      Compliance Status = Pass
============== End of Requirement 4.6 ==============


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

name = Akash
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 19.900000
Thermal Mass = 19.900000
Diameter/Width = 0.500000
Length = 0.721000
Height = 0.300000

name = X Radiator Panels
quantity = 2
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.620000
Thermal Mass = 0.620000
Diameter/Width = 0.200000
Length = 0.300000

name = Y Radiator Panels
quantity = 2
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.620000
Thermal Mass = 0.620000
Diameter/Width = 0.200000
Length = 0.300000

name = Avionics Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 4.820000
```

```
Thermal Mass = 4.820000
Diameter/Width = 0.200000
Length = 0.200000
Height = 0.100000

name = Solar Array Panels
quantity = 2
parent = 1
materialID = 24
type = Flat Plate
Aero Mass = 1.500000
Thermal Mass = 1.500000
Diameter/Width = 0.300000
Length = 0.400000

name = Akash Transmitter
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 5.000000
Thermal Mass = 5.000000
Diameter/Width = 0.200000
Length = 0.300000
Height = 0.100000

name = Payload Battery
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.500000
Thermal Mass = 1.500000
Diameter/Width = 0.100000
Length = 0.150000
Height = 0.100000

name = Bus Battery
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.750000
Thermal Mass = 0.750000
Diameter/Width = 0.065000
Length = 0.147000
Height = 0.037000

name = Akash Antenna
quantity = 1
parent = 1
```

AKASH SYSTEMS

```
materialID = 8
type = Cylinder
Aero Mass = 1.500000
Thermal Mass = 1.500000
Diameter/Width = 0.116600
Length = 0.500000

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

name = Akash
Demise Altitude = 77.994820
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = X Radiator Panels
Demise Altitude = 73.681236
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Y Radiator Panels
Demise Altitude = 73.681236
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Avionics Box
Demise Altitude = 54.511780
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Solar Array Panels
Demise Altitude = 0.000000
Debris Casualty Area = 1.791384
Impact Kinetic Energy = 306.250244

************************************
name = Akash Transmitter
Demise Altitude = 60.755245
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Payload Battery
Demise Altitude = 67.506790
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

AKASH SYSTEMS

```
************************************
name = Bus Battery
Demise Altitude = 68.241615
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Akash Antenna
Demise Altitude = 72.775955
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************

=============== End of Requirement 4.7-1 ===============
```

AKASH SYSTEMS

# Submitted By:

*Whitney Lohmeyer*

Whitney Lohmeyer
Regulatory Consultant, Lohmeyer Consulting LLC