

Sapling Final Orbital Debris Assessment Report (ODAR)

### Approved by Co-Presidents Flynn Dreilinger and Rahma Ali

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### Prepared by Isobel Porteous, Sats Team Co-lead

### Report generated with NASA DAS 3.2.1 and written in accordance with NASA-STD-8719.14[[1]](#footnote-0)

# Revision History

| Revision | Description | Release Date |
| --- | --- | --- |
| 1 | Initial release | June 20, 2022 |

# 

# Section 1: Program and Mission Overview

| ODAR Author | Isobel Porteous ([idp2024@stanford.edu](mailto:idp2024@stanford.edu)) |
| --- | --- |
| Mission Managers | Flynn Dreilinger ([flynnd@stanford.edu](mailto:flynnd@stanford.edu))  Jacob Mukobi ([jmukobi@stanford.edu](mailto:jmukobi@stanford.edu))  Isobel Porteous ([idp2024@stanford.edu](mailto:idp2024@stanford.edu))  Grant Regen ([gregen@stanford.edu](mailto:gregen@stanford.edu)) |
| Mission Description | The overall goal of the Sapling mission is to prove critical subsystems of the Sapling CubeSat Bus. The Sapling project is entirely open source and developed by members of the Stanford Student Space Initiative, a primarily undergraduate volunteer student engineering organization at Stanford University. Secondary mission goals are demonstrating autonomous cloud filtering and smart downlinking of images, and proving that the inexpensive COTS Google Coral Edge computing platform is more efficient at image processing and makes up for use of silicon cells that are less efficient than much higher priced GaAS cells.  Development of the Sapling Bus supports our research of autonomous machine learning algorithms for ecological research and forest fire prediction. In addition, we are planning to fly the Sapling Bus as part of the Pleiades satellite swarm for optical navigation, in collaboration with Cal Poly Pomona, Portland State University, and University of Hawaii. |
| Foreign Government Involvement | None |
| Project Milestones | Spring 2022: Design and Fabrication  May 2022: Qualification Testing  September 2022: Shipment and Integration  November 7th 2022: Launch  October/December 2022: Deployment and Operations  December-June 2022: Mission lifetime  2025-2027: Deorbit due to natural orbital decay |
| Range and orbital elements | 525km SSO Polar Orbit, 10:00 LTDN  (SpaceX Transporter 6) |
| Launch information | Proposed date: November 7th, 2022  Proposed site: Cape Canaveral, Florida  Launch Vehicle: Falcon 9 |
| Maneuver Capability and Potential Physical Interference with Other Objects | The Sapling bus has no propulsion systems and its orbit will decay naturally over time. It presents no risk of interference with other spacecraft beyond the collision risks outlined in section 5, which are all compliant with NASA-STD-8719.14A.[[2]](#footnote-1) |

# Section 2: Spacecraft Description

The Sapling spacecraft is a 1U CubeSat, with an overall size of 10 cm x 10 cm x 11 cm. The total mass is about 1.07 kg, and the COM will fall within Cal Poly Specifications. Sapling is designed to operate in LEO, and be commissioned from a standard CubeSat deployment mechanism.

| Form Factor | 1U Cubesat |
| --- | --- |
| Radioactive materials | None |
| Proximity operations planned | None |
| Propulsion Systems | None |
| Guidance, Navigation, and Control | 6 coarse sun sensors, a 3-axis Bosch magnetometer, PCB magnetorquers for attitude control, and a Skytraq GPS with dual Taoglas antennas |
| Command and Data Handling | PyCubed V5.01 |

# Section 3: Assessment of Debris Released During Normal Operations

The only debris generated during Sapling’s nominal operations is burnup of a small piece of fishing line during antenna deployment. This debris generated at deployment has been determined to fall within the NASA-STD-8719.14A[[3]](#footnote-2) restrictions, given its small mass and diameter.

| Requirement | Compliance |
| --- | --- |
| 4.3-1: Debris passing through LEO – released debris with diameters of 1mm or larger: | |
| 4.3-1a: All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release. | COMPLIANT |
| 4.3-1b: The total object-time product shall be no larger than 100 object years per mission. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to collectively follow the same 100 object-years per mission deployment limit. | COMPLIANT |
| 4.3-2: Debris passing near GEO: For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude +/- 200 km and +/- 15 degrees inclination), released debris with diameters of 5 mm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO - 200 km or the perigee will not be lower than GEO + 200 km , and also ensures that the debris is incapable of being perturbed to lie within that GEO +/- 200 km and +/- 15 zone for at least 100 years thereafter. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to follow this requirement. | N/A |

# Section 4: Assessment of Debris Generated by Explosions and Intentional Breakups

Energy release from onboard batteries constitutes the only potential cause of accidental explosion or spacecraft breakup. We see this risk as the only probable failure mode that could jeopardize other space systems. The Sapling mission is not designed for any intentional spacecraft breakup.

The Sapling satellite contains 6 cells of the Panasonic NCR18650B 3400mAh 4.9A Battery. These batteries were chosen under consideration of the 2015 NASA findings on Safe, High Performing Li-ion Battery Designs.[[4]](#footnote-3) Sapling also utilizes the 2S3P Li-Ion battery board which meets maximum capacity requirements of common CubeSat integrators and uses components with radiation testing heritage, including R5460N233AF for protection against over-charge, over-discharge, short-circuit, excess discharge-current, and excess charge-current. Sapling is designed to power off batteries in the event that thermal conditions exceed those recommended for this battery model. Based on this failure mitigation plan and the testing done on the chosen battery model, we deem the risk of spacecraft breakup due to battery failure to be low.

In light of the limited risk of spacecraft breakup or accidental explosion as discussed above, as well as the low collision risk data as assessed using NASA DAS, we deem Sapling to pose very low risk to other spacecraft.

| Requirement | Compliance |
| --- | --- |
| 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: For each spacecraft and launch vehicle orbital stage employed for a mission (i.e., every individual free-flying structural object), the program or project shall demonstrate, via failure mode and effects analyses, probabilistic risk assessments, or other appropriate analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle does not exceed 0.001 (excluding small particle impacts.). | COMPLIANT |
| 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth, or the Moon: Design of all spacecraft and launch vehicle orbital stages shall include the ability and a plan to either 1) deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or postmission disposal or 2) control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft. The design of depletion burns and ventings should minimize the probability of accidental collision with tracked objects in space. | N/A |
| 4.4-3: Limiting the long-term risk to other space systems from planned breakups for Earth and lunar missions: Planned explosions or intentional collisions shall: | |
| 4.4-3a: be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product does not exceed 100 object-years. For example, if the debris fragments greater than 10cm decay in the maximum allowed 1 year, a maximum of 100 such fragments can be generated by the breakup. | N/A |
| 4.4-3b: Not generate debris larger than 1 mm that remains in Earth orbit longer than one year. | N/A |
| 4.4-4: Limiting the short-term risk to other space systems from planned breakups for Earth orbital missions: Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be verified to not exceed 10-6. | N/A |

# Section 5: Assessment of Debris Generated by On-Orbit Collision

The risk of on-orbit collision during Sapling’s orbital lifetime has been assessed using NASA DAS version 3.2.1 and found to be compliant with requirement 4.5-1 in the Process for Limiting Orbital Debris[[5]](#footnote-4) in any possible configuration.

| Configuration | Area to Mass Ratio (m2/kg) | Collision Risk (large debris) |
| --- | --- | --- |
| Min. Area to Mass  Max. Area to Mass | 0.00935  0.0173 | 1.239 x 10-7  1.602 x 10-7 |

Assessment of spacecraft compliance with Requirement 4.5-1 and 4.5-2:

| Requirement | Compliance |
| --- | --- |
| 4.5-1, Limiting debris generated by collisions with large objects when in Earth orbit: For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter does not exceed 0.001. For spacecraft and orbital stages passing through the protected region +/- 200 km and +/-15 degrees of geostationary orbit, the probability of accidental collision with space objects larger than 10 cm in diameter shall not exceed 0.001 when integrated over 100 years from time of launch. | COMPLIANT |
| 4.5-2, Limiting debris generated by collisions with small objects when operating in Earth orbit: For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post mission disposal maneuver requirements does not exceed 0.01. | N/A |

# Section 6: Post-Mission Disposal of Space Structures

For edge case configuration and orientation, Sapling’s orbital dwell time was calculated using NASA DAS 3.2.1:

| Configuration | Area to Mass (m2/kg) | Orbital Lifetime (years) |
| --- | --- | --- |
| Min. Area to Mass  Max. Area to Mass | 0.00935  0.0173 | 5.465  3.039 |

The satellite does not require any post-mission disposal systems or maneuvers, and there is no planned variation in area to mass ratio over the mission lifetime. In accordance with requirement 4.6-1 in the Orbital Debris Mitigation Standard, our post mission disposal plan is to allow for atmospheric reentry and burnup due to orbital decay.

| Requirement | Compliance |
| --- | --- |
| 4.6-1. Disposal for space structures in or passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2,000 km shall be disposed of by one of the following 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 or  (2) Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.  b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude above 2000 km and ensure its apogee altitude will be below 19,700 km, both for a minimum of 100 years.  c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission. | COMPLIANT |
| 4.6-2. Disposal for space structures near GEO: A spacecraft or orbital stage in an orbit near GEO shall be maneuvered at EOM to a disposal orbit above GEO with a predicted minimum perigee of GEO +200 km (35,986 km) or below GEO with a predicted maximum apogee of GEO – 200 km (35,586 km) for a period of at least 100 years after disposal. | N/A |
| 4.6-3. Disposal for space structures between LEO and GEO: 4.6.2.3.1 Between LEO and Medium Earth Orbit (MEO): A spacecraft or orbital stage shall be left in an orbit with a perigee altitude greater than 2000 km and apogee altitude below 19,700 km for 100 years. 4.6.2.3.2 Between MEO and GEO: A spacecraft or orbital stage shall be left in an orbit with a perigee altitude greater than 20,700 km and apogee altitude below 35,300 km for 100 years. | N/A |
| 4.6-4. Reliability of postmission disposal maneuver operations in Earth orbit: NASA space programs and projects shall ensure that all postmission disposal operations to meet Requirements 4.6-1, 4.6-2, and/or 4.6-3 are designed for a probability of success as follows: a. Be no less than 0.90 at EOM, and b. For controlled reentry, the probability of success at the time of reentry burn must be sufficiently high so as not to cause a violation of Requirement 4.7-1 pertaining to limiting the risk of human casualty. | N/A |

# Section 8: Additional Assessment Requirements for Tether Missions

N/A

# Appendix

### DAS Log File

05 08 2022; 12:20:45PM Activity Log Started

05 08 2022; 12:20:45PM Project Data Saved To File

05 08 2022; 13:08:35PM Project Data Saved To File

05 08 2022; 13:08:42PM Project Data Saved To File

05 08 2022; 13:08:42PM Project Data Saved To File

05 08 2022; 13:33:48PM Activity Log Started

05 08 2022; 13:33:48PM Opened Project C:\Users\ssi\AppData\Local\NASA\DAS3.2.1\

05 08 2022; 13:34:17PM Project Data Saved To File

05 08 2022; 13:34:43PM Project Data Saved To File

05 08 2022; 13:34:51PM Project Data Saved To File

05 08 2022; 13:34:52PM Project Data Saved To File

05 08 2022; 13:34:54PM Project Data Saved To File

05 08 2022; 13:34:57PM Project Data Saved To File

05 08 2022; 13:35:05PM Project Data Saved To File

05 08 2022; 13:35:07PM Project Data Saved To File

05 08 2022; 13:35:13PM Project Data Saved To File

05 08 2022; 13:35:18PM Project Data Saved To File

05 08 2022; 13:35:21PM Project Data Saved To File

05 08 2022; 13:35:32PM Project Data Saved To File

05 08 2022; 13:35:36PM Project Data Saved To File

05 08 2022; 13:35:39PM Project Data Saved To File

05 08 2022; 13:35:45PM Project Data Saved To File

05 08 2022; 13:36:24PM Mission Editor Changes Applied

05 08 2022; 13:36:24PM Project Data Saved To File

05 08 2022; 13:36:24PM Project Data Saved To File

05 08 2022; 13:37:02PM Processing Requirement 4.3-1: Return Status : Not Run

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No Project Data Available

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=============== End of Requirement 4.3-1 ===============

05 08 2022; 13:38:04PM 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 ===============

05 08 2022; 13:38:09PM 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 ===============

05 08 2022; 13:50:25PM Processing Requirement 4.5-1: Return Status : Passed

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Run Data

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\*\*INPUT\*\*

Space Structure Name = Sapling Min Area

Space Structure Type = Payload

Perigee Altitude = 525.000 (km)

Apogee Altitude = 525.000 (km)

Inclination = 98.700 (deg)

RAAN = 0.000 (deg)

Argument of Perigee = 0.000 (deg)

Mean Anomaly = 0.000 (deg)

Final Area-To-Mass Ratio = 0.0094 (m^2/kg)

Start Year = 2022.830 (yr)

Initial Mass = 1.070 (kg)

Final Mass = 1.070 (kg)

Duration = 5.465 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

\*\*OUTPUT\*\*

Collision Probability = 1.2389E-07

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

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

\*\*INPUT\*\*

Space Structure Name = Sapling Max Area

Space Structure Type = Payload

Perigee Altitude = 525.000 (km)

Apogee Altitude = 525.000 (km)

Inclination = 98.700 (deg)

RAAN = 0.000 (deg)

Argument of Perigee = 0.000 (deg)

Mean Anomaly = 0.000 (deg)

Final Area-To-Mass Ratio = 0.0173 (m^2/kg)

Start Year = 2022.830 (yr)

Initial Mass = 1.070 (kg)

Final Mass = 1.070 (kg)

Duration = 3.039 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

\*\*OUTPUT\*\*

Collision Probability = 1.6018E-07

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

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=============== End of Requirement 4.5-1 ===============

05 08 2022; 13:52:03PM Project Data Saved To File

05 08 2022; 13:52:08PM Requirement 4.5-2: Compliant

=============== End of Requirement 4.5-2 ===============

05 08 2022; 13:52:17PM Processing Requirement 4.6 Return Status : Passed

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Project Data

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\*\*INPUT\*\*

Space Structure Name = Sapling Min Area

Space Structure Type = Payload

Perigee Altitude = 525.000000 (km)

Apogee Altitude = 525.000000 (km)

Inclination = 98.700000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.009350 (m^2/kg)

Start Year = 2022.830000 (yr)

Initial Mass = 1.070000 (kg)

Final Mass = 1.070000 (kg)

Duration = 5.465000 (yr)

Station Kept = False

Abandoned = True

PMD Perigee Altitude = 144.090187 (km)

PMD Apogee Altitude = 147.559516 (km)

PMD Inclination = 98.640501 (deg)

PMD RAAN = 179.921908 (deg)

PMD Argument of Perigee = 112.936178 (deg)

PMD Mean Anomaly = 0.000000 (deg)

Long-Term Reentry = False

\*\*OUTPUT\*\*

Suggested Perigee Altitude = 144.090187 (km)

Suggested Apogee Altitude = 147.559516 (km)

Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2028 (yr)

Requirement = 61

Compliance Status = Pass

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\*\*INPUT\*\*

Space Structure Name = Sapling Max Area

Space Structure Type = Payload

Perigee Altitude = 525.000000 (km)

Apogee Altitude = 525.000000 (km)

Inclination = 98.700000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.017300 (m^2/kg)

Start Year = 2022.830000 (yr)

Initial Mass = 1.070000 (kg)

Final Mass = 1.070000 (kg)

Duration = 3.039000 (yr)

Station Kept = False

Abandoned = True

PMD Perigee Altitude = 169.942569 (km)

PMD Apogee Altitude = 174.614093 (km)

PMD Inclination = 98.644104 (deg)

PMD RAAN = 214.378300 (deg)

PMD Argument of Perigee = 107.965743 (deg)

PMD Mean Anomaly = 0.000000 (deg)

Long-Term Reentry = False

\*\*OUTPUT\*\*

Suggested Perigee Altitude = 169.942569 (km)

Suggested Apogee Altitude = 174.614093 (km)

Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2025 (yr)

Requirement = 61

Compliance Status = Pass

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=============== End of Requirement 4.6 ===============

05 08 2022; 16:31:53PM Project Data Saved To File

1. ‘Process for Limiting Orbital Debris’, NASA, 2021

   Available: <https://standards.nasa.gov/sites/default/files/standards/NASA/C/0/nasa-std-871914c.pdf> [↑](#footnote-ref-0)
2. ‘Process for Limiting Orbital Debris’, NASA, 2021

   Available: <https://standards.nasa.gov/sites/default/files/standards/NASA/C/0/nasa-std-871914c.pdf> [↑](#footnote-ref-1)
3. ‘Process for Limiting Orbital Debris’, NASA, 2021

   Available: <https://standards.nasa.gov/sites/default/files/standards/NASA/C/0/nasa-std-871914c.pdf> [↑](#footnote-ref-2)
4. Darcy, E. and Scharf S., ‘Safe, High Performing Li-ion Battery Designs: Summary of 2015 Findings’, Huntsville, AL, NASA, 2015,

   Available: <https://www.nasa.gov/sites/default/files/atoms/files/darcy_-_nasa_batt_workshop_2015.pdf> [↑](#footnote-ref-3)
5. ‘Process for Limiting Orbital Debris’, NASA, 2021

   Available: <https://standards.nasa.gov/sites/default/files/standards/NASA/C/0/nasa-std-871914c.pdf> [↑](#footnote-ref-4)