ELVL-2020-0045755
June 9, 2020

Orbital Debris Assessment for The TARGIT CubeSat per NASA-STD 8719.14A

Signature Page

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ELVL-2019-0045755

Reply to Attn of: VA-H1

June 9, 2020

TO: Scott Higginbotham, LSP Mission Manager, NASA/KSC/VA-C

FROM: Yusef Johnson, a.i. solutions/KSC/AIS2

SUBJECT: Orbital Debris Assessment Report (ODAR) for the TARGIT Mission

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6B, 6 February 2017
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14B, 25 April 2019
C. International Space Station Reference Trajectory, delivered May 2019
D. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 5th ed. Northbrook, IL, Underwriters Laboratories, 2012
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014
I. ODPO Guidance Email: Fasteners and Screws, John Opiela to Yusef Johnson, 12 February 2020

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the TARGIT CubeSat launching on the SpX-23 Falcon 9 launch vehicle. It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the primary mission and are not presented here.

This report serves as the the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the primary mission and are not presented here. This CubeSat will passively reenter, and therefore this ODAR will also serve as the End of Mission Plan (EOMP) for this CubeSat.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	June 2020

Section 1: Program Management and Mission Overview

TARGIT is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is John Guidi. Responsible program/project manager and senior scientific and management personnel are as follows:

Dr. Brian Gunter, Principal Investigator, Georgia Tech Research Corporation

The following table summarizes the compliance status of TARGIT, which will be flown to and deployed from the International Space Station. TARGIT is fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Not applicable	No planned debris release
4.3-1b	Not applicable	No planned debris release
4.3-2	Not applicable	No planned debris release
4.4-1	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-2	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Not applicable	
4.6-1(a)	Compliant	Worst case lifetime 2.23 yrs
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	Tether is released at low altitude (250 km) and deorbits within days

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	October, 2019
Delivery to Nanoracks	January 2021
Launch	NET May 2021

Figure 1: Program Milestone Schedule

TARGIT will be launched as a payload on the Space Falcon 9 launch vehicle executing the Spx-23 mission. The current launch date is projected to be NET May 2021

Section 2: Spacecraft Description

TARGIT is flying as part of a to-be-determined mission complement. Table 2 outlines its generic attributes.

Table 2: TARGIT Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Mass(kg)
TARGIT	1	340.5 x 100 x 100	4.71

The following pages describe the TARGIT CubeSat.

TARGIT – Georgia Institute of Technology – 3U

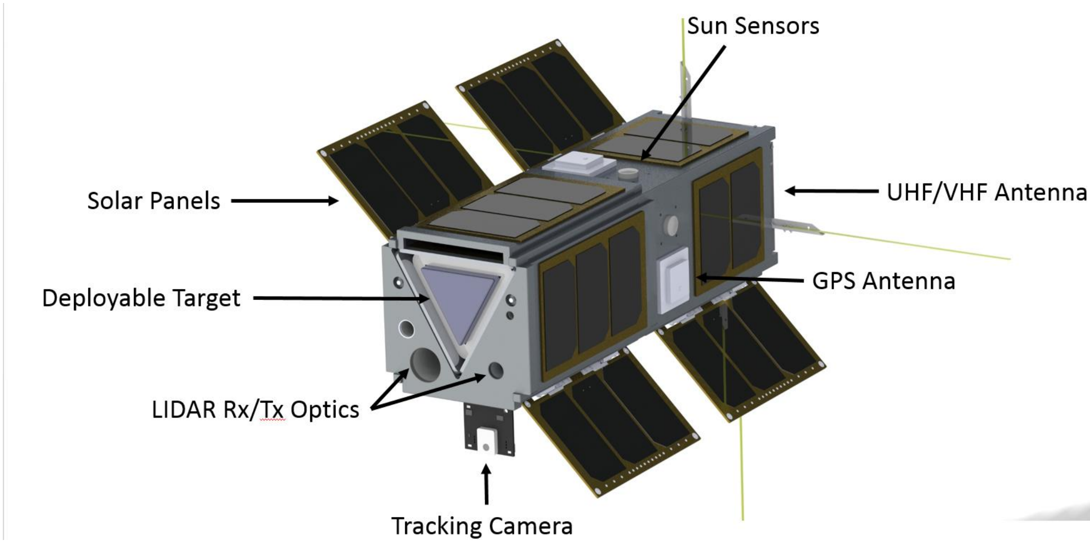

Figure 2: TARGIT assembled view

Overview

The Tethering and Ranging mission of the Georgia Institute of Technology (TARGIT) is a 3U CubeSat mission seeks to test on-orbit an imaging LiDAR system capable of cm-level topographic mapping. The mission will accomplish this by tethering an inflatable target of known shape and reflectance that will serve to verify the performance of the imaging LiDAR and its supporting subsystems. The target will be tracked with an optical imager that will provide input to the attitude control system. In addition, the attitude control system will make sure of experimental low-resolution thermal imagers as horizon detectors to maintain spacecraft orientation while in eclipse.

CONOPS

Upon deployment from the ISS, TARGIT will power up and start counting down timers. At 30 minutes, the antennas will be deployed and the UHF beacon will be activated. Following initial system checkouts, mission operations will proceed as follows, as illustrated below:

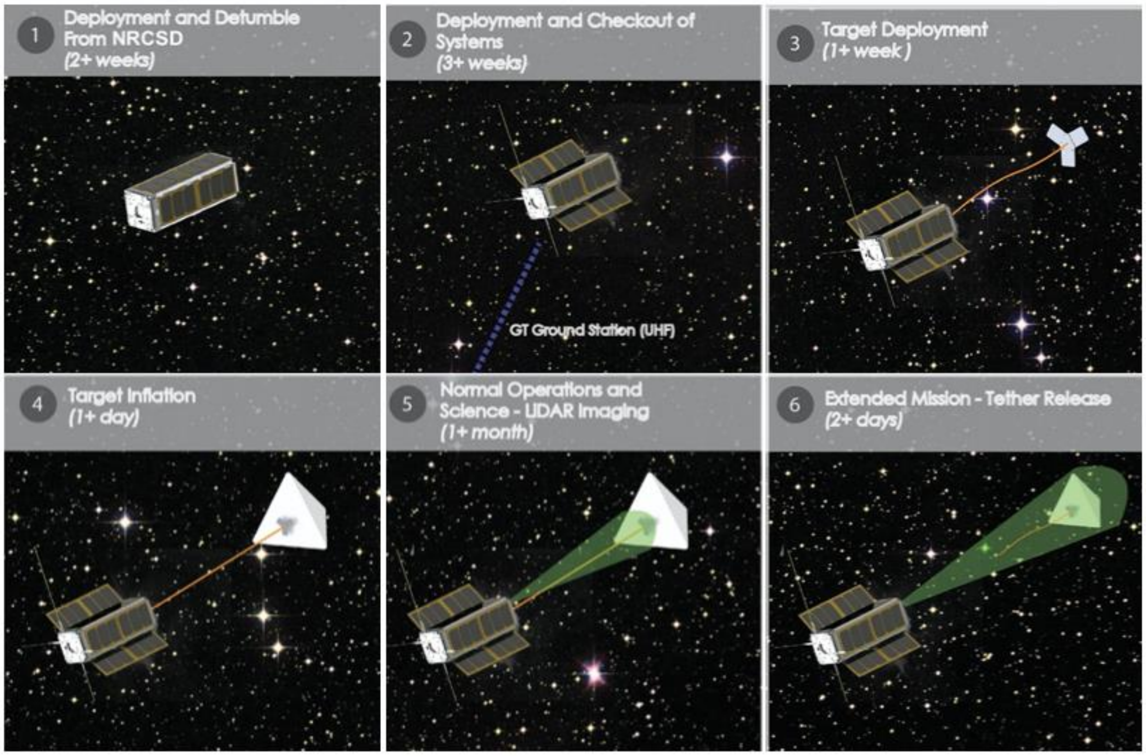

Figure 3: TARGIT CONOPS

The initial mission phase (1) will consist primarily of detumble, checks of basic housekeeping data, and battery charging, lasting approximately 2 weeks. The next phase (2) will deploy the solar panels and run more extensive subsystem checkouts and diagnostics, to include the lidar payloads, over a period of approximately 3 weeks. Once all systems have been verified, the target deployment will begin (phase 3). This will first consist of pushing the target out of the main spacecraft with the lead screw, and then subsequent operation of the active tether system. All of these events will be initiated and controlled by ground commands.

To avoid bounceback of the target to the main spacecraft, we anticipate the tether deployment to go very slowly, on the order of a few centimeters per orbit, or around 1 meter per day. That will give us plenty of time to inspect the deployment with the visible-spectrum camera. If necessary, target inflation may be done early to create a stabilizing drag force on the target assembly during tether deployment. The tether length is nominally 6 meters, so one week is budgeted the full tether deployment sequence (lead screw plus active tether). The inflation of the target (phase 4), if not done during tether deployment, will also be done in stages, but is not expected to take more than one day.

Once the target is fully deployed and inflated, the orbit lifetime of the mission decreases significantly, to approximately 1-2 months. During this period, primary mission operations take place in which the target is imaged by the lidar camera, and the mission data is downlinked to the Georgia Tech ground station (phase 5). Additional secondary experiments, such as validation of custom sun and horizon sensors, will also be performed during this period. After all primary mission objectives have been satisfied, the final phase (6) of the mission will be to cut the tether and continue to image and range to the free-floating target for as long as possible. This scenario is representative of targeting and tracking of a remote planetary object (comet, asteroid, planetary feature), which is another important objective for the mission. Once the tether is cut, the target is not expected to stay within 10 km of the main spacecraft for more than 8-12 hours, depending on the altitude and drag environment. This final mission phase will likely take place within 1-3 weeks of spacecraft reentry, at an altitude not to exceed 250km, and is a commanded event, so can be coordinated for favorable ground station/optical viewing geometries. The TARGIT main body is expected to re-enter ~ 6 weeks after the tether is disengaged. The target assembly and tether are expected to re-enter ~3 days after being disengaged.

Materials

Nearly all materials on the spacecraft are standard materials such as 6061 aluminum, electronic circuit boards, copper wire, optical glass, or 18-8 stainless steel metal fasteners. The primary non-standard materials being flown are the aluminized mylar used by the inflatable and the Somos PerFORM 3D printed material for the tank.

Hazards

There are two laser systems on board the CubeSat. One is 1550 nm and the other is 532 nm. Both are laser systems classified as eye-safe. The tank that will be used to inflate the mylar target will have a volume of 11.4 cm^3 with less than 50 psi of GN_2.

Batteries

The satellite has a primary battery pack with four 18650 cylindrical lithium-ion cells, and one 18500 cylindrical lithium-ion cell resides in the deployed target. There is an additional coin-cell battery on the main breakout board. All batteries used comply with the UN Model Regulations, Manual of Test and Criteria, subsection 38.3. In addition, the cylindrical lithium-ion batteries will undergo flight acceptance testing in accordance with the procedures described in NanoRacks document NR-SRD-139 RevC “Flight Acceptance Test Requirements for Lithium-ion Cells and Battery Packs.”, satisfying ISS Program standards.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

The section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

TARGIT has a target with, once deployed, will be tethered to the CubeSat, in order to facilitate additional scientific observations. Once the spacecraft reaches an altitude of 250 km, it will be detached. The predicted orbit at the target detachment event will have a apogee of ~265.2 km and a perigee of ~250 km. Once detatched, the target will deorbit within approximately 3 days.

The TARGIT target assembly and tether, as detached, is compliant with Requirements 4.3-1 and 4.3-2.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions for TARGIT.

The probability of battery explosion is very low, and, due to the very small mass of the satellites and their short orbital lifetimes the effect of an explosion on the far-term LEO environment is negligible (ref (h)).

The CubeSats batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy regarding CubeSat battery disconnect stating;

> "CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years." (ref. (h))

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, the low charges and small battery cells on the CubeSat's power system prevent a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum lifetime of ~2.23 years maximum, each of the configurations of TARGIT are compliant.

Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.

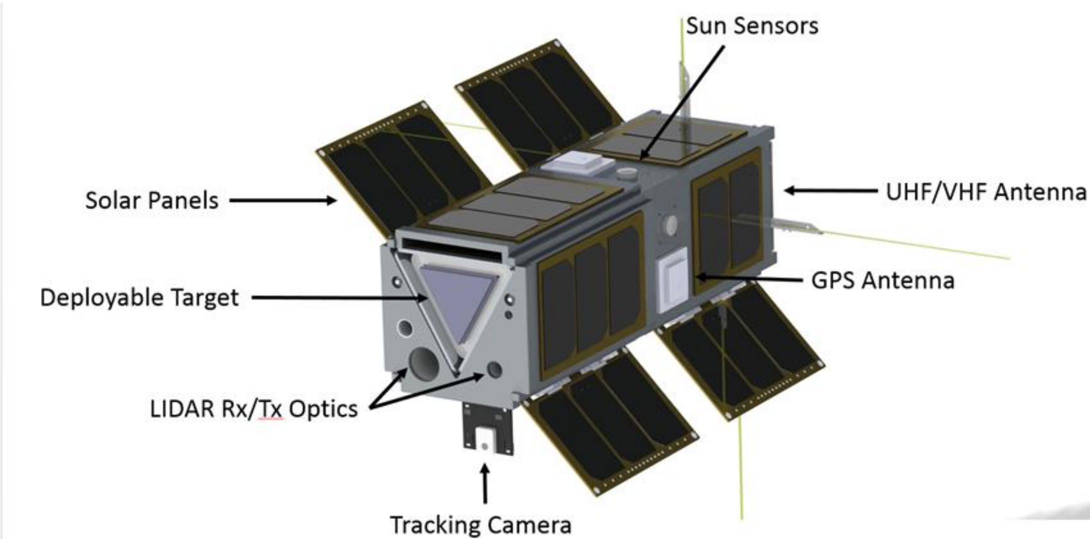

Figure 4: TARGIT Assembled View

$$\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\mathbf{4}} = \frac{[\mathbf{2} * (\boldsymbol{w} * \boldsymbol{l}) + \mathbf{4} * (\boldsymbol{w} * \boldsymbol{h})]}{\mathbf{4}}$$

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\boldsymbol{Mean\ CSA} = \frac{(\boldsymbol{A_{max}} + \boldsymbol{A_1} + \boldsymbol{A_1})}{\mathbf{2}}$$

Equation 2: Mean Cross Sectional Area for Complex Objects

TARGIT has multiple configurations, which determine how the cross-sectional area was determined. Probability of collision and lifetime calculations were determined for each configuration using the appropriate cross-sectional area.

TARGIT's expected (4.71 kg) orbit at deployment has a 424 km apogee and a 410 km perigee. With an area to mass ratio of ~.006 m^2/kg, DAS yields 1.02 years for orbit lifetime for its as-deployed state. This as-deployed state lifetime is then used to perform collision probability calculations. TARGIT, in its as-deployed state, has a probability of collision of 0.0. This calculation assumes that TARGIT is in an unstable state.

Following a stabilization period, TARGIT will deploy its solar panels approximately 2 weeks following ejection from the ISS. When this event occurs, the CubeSat will be is an orbit with an apogee of 427.5 km and a perigee of 404.3 km. This cross sectional area of this configuration has an area to mass ratio of .00212 m^2/kg. DAS yields a 2.23 years lifetime for this configuration, which also yields the longest orbital lifetime. The probability of collision in this configuration is 0.0

Three weeks after solar panel deploy, the target balloon is deployed at an orbit that is estimated to have an apogee of 433 km and a perigee of 397.2 km. At this point, the CubeSat is stable and oriented, with the ram face being the short side of the spacecraft. The total area to mass of this configuration is .214 m^2/kg. This configuration has an orbital lifetime of ~2.9 weeks. The probability of collision calculation of this configuration is 0.0.

Approximately 2 weeks after the target balloon is deployed, TARGIT will be in an orbit that has a 265.2 km apogee and a 250 km perigee. Upon reaching this orbit, the target balloon will be disengaged from the main body of the CubeSat. The target balloon has a cross sectional area of 10.31 m^2/kg and will re-enter ~3 days after being disengaged from the TARGIT main body. The probability of collision for the target assembly and tether is 0.0.

The TARGIT main body, sans the target balloon assembly, has an area to mass ratio of .00216 m^2/kg. This configuration will remain in orbit for approximately 6 weeks before it to re-enters. The probability of collision of this configuration is also 0.0.

Table 3 below provides complete results.

There will be no post-mission disposal operation. As such, the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable

CubeSat		TARGIT
	Initial Mass (kg)	4.7
Stowed	**Mean C/S Area (m^2)**	0.027
	Area-to Mass (m^2/kg)	0.0057
	Orbital Lifetime (yrs)	**1.02**
	Probability of collision (10^X)	**0.0000**
Solar Panels Deployed	**Mean C/S Area (m^2)**	0.01
	Area-to Mass (m^2/kg)	0.0021
	Orbital Lifetime (yrs)	**2.23**
	Probability of collision (10^X)	**0.0000**
TARGIT w/target Deployed	**Mean C/S Area (m^2)**	1.01
	Area-to Mass (m^2/kg)	0.2143
	Orbital Lifetime (yrs)	**0.055**
	Probability of collision (10^X)	**0.0000**
TARGIT post-disconnect	**Mean C/S Area (m^2)**	.01
	Area-to Mass (m^2/kg)	0.0022
	Orbital Lifetime (yrs)	**0.110**
	Probability of collision (10^X)	**0.0000**

Table 3: CubeSat Orbital Lifetime & Collision Probability

Balloon post-disconnect	**Mean C/S Area (m^2)**	1
	Area-to Mass (m^2/kg)	10.31
	Orbital Lifetime (yrs)	**~ 3 days**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Generated 3/27/2020

Table 3: CubeSat Orbital Lifetime & Collision Probability (cont.)

The probability of TARGIT colliding with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than 0.00000, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows TARGIT to be compliant. Requirement 4.5-2 is not applicable to this mission.

TARGIT has no capability or plans for end-of-mission disposal, therefore Requirement 4.5-2 is not applicable. TARGIT will passively reenter and therefore this ODAR also serves as the EOMP (End of Mission Plan)

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

TARGIT will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal has TARGIT in its stable solar panels deployed configuration as the worst case. The area-to-mass is calculated for is as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}/_{\boldsymbol{S}}\,\boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area-to-Mass}\ (\frac{\boldsymbol{m^2}}{\boldsymbol{kg}})$$

Equation 3: Area to Mass

$$\frac{0.01m^2}{4.71\ kg} = \ 0.002\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS Orbital Lifetime Calculations:</u>
DAS inputs are: 427.5 km maximum apogee 404.3 km maximum perigee altitudes with an inclination of 51.6º ,with solar panel deployed, no earlier than March 2021. An area to mass ratio of ~0.002 m^2/kg for the TARGIT CubeSat was used. DAS yields a 2.23 years orbital lifetime for TARGIT in its stable, solar panels deployed state.

This meets requirement 4.6-1. For the complete list of orbital lifetimes, reference Table 3

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on TARGIT was performed. The assessment used DAS, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry, it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it is expected to possess the same negligible risk as stainless steel components.

3. Fasteners and similar materials that are composed of stainless steel or a lower melting point material will not be input into DAS, as suggested by guidance from the Orbital Debris Project Office (Reference I)

Table 4: TARGIT High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Torque rods (horizontal, vertical)	Copper and iron	.166	66.3	-
Lead screw motor	Copper and iron w/stainless steel housing	.103	68.5	-
Tuna can antenna plate	Stainless steel	.035	0	2
Lead screw	Stainless steel	.017	0	.69
Threaded tension rod	Stainless steel	.059	0	.2
Tether motor	Stainless steel	.033	71.2	-
Helicoil inserts	Stainless steel	.08	75.0	-
GPS Patch antenna	Ceramic	.0235	77.5	
Target valves	Stainless steel	.011	76.8	-
Magnetometer	Permalloy	.00131	0.0	0

The majority of high temperature components demise upon reentry and TARGIT complies with the 1:10,000 probability of Human Casualty Requirement 4.7-1. A breakdown of the determined probabilities follows:

Table 5: Requirement 4.7-1 Compliance by CubeSat

Name	Status	Risk of Human Casualty
TARGIT	Compliant	1:0

*Requirement 4.7-1 Probability of Human Casualty > 1:10,000

If a component survives to the ground but has less than 15 Joules of kinetic energy, it is not included in the Debris Casualty Area that inputs into the Probability of Human Casualty calculation. This is why TARGIT has a 1:0 probability, as none of its components has more than 15J of energy.

TARGIT is compliant with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

TARGIT will be deploying a tether. This tether, which is 6 m long and has a diameter of 16 mm, is connected to a target balloon, which will be used for scientific observations.

Upon reaching an orbital altitude of 250 km, which is estimated to be approximately 8 weeks following ejection from the ISS per the conops, the tether will be disconnected from the main CubeSat body, but will remain connected to the target balloon. This target balloon is predicted to have a very short orbital lifetime (~3 days) once disconnected from the main body CubeSat at an altitude of 250km.

The maximum cross sectional area of the tether is .045 m^2. This area is considered negligible as compared to the area of the target balloon, which is $1m^2$, for orbital lifetime and collision risk calculations.

TARGIT is compliant with Section 8's requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here. Launch vehicle sections of the ODAR are the responsibility of the CRS provider.

If you have any questions, please contact the undersigned at 321-867-2098.

/original signed by/

Yusef A. Johnson
Flight Design Analyst
a.i. solutions/KSC/AIS2

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-C/Mrs. Nufer
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. TARGIT Component List

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	TARGIT 3U		6061 Aluminum	Box	4712.89	100	340.5	100	No	-	-
2	MAI-400 Reaction Wheels	3	Aluminum 6061-T6	Box	369.00	33	38	33	No	-	Demise
3	Top structure	1	Aluminum 6061-T6	Box	329.00	100	100	150	No	-	Demise
4	NanoPower BP4 battery pack	1	FR4 & Li-ion	Box	268.30	88	93.0	23	No	-	Demise
5	Target enclosure panels	3	Alodined Aluminum 6061-T6	Plate	249.00	58	110.0	3	No	-	Demise
6	Bottom structure	1	Aluminum 6061-T6	Box	192.10	100	100	150	No	-	Demise
7	Solar Panel PCB (deploy)	4	FR4	Plate	171.60	80	146.0	1.6	No	-	Demise
8	Torque rods - Horizontal	2	Copper and iron	Cylinder	166.40	16.2	50	16.2	Yes	2800°	Demise
9	Connecting bracket	1	Aluminum 6061-T6	Box	159.50	100	100	10	No	-	Demise
10	Tuna Can housing	1	Aluminum 6061-T6	Cylinder	156.60	45.0	88.0	88.0	No	-	Demise
11	Target Tank	1	Somos PerFORM	Box	147.82	58	110.0	51	No	-	Demise
12	Laser controller	1	Hard Anodized Aluminum 6061-T6 & FR4	Box	128.00	58	99.0	20	No	-	Demise
13	Lead screw motor	1	Copper and iron core with stainless steel housing	Cylinder	103.00	23	72	23	Yes	2500°	Demise
14	NanoPower p31us	1	FR4	Plate	98.50	10	10.0	1.6	No	-	Demise
15	Solar Cells	24	GalnP2/lnGaAs/Ge/Germanium substrate	Plate	86.40	40	65.0	0.5	No	-	Demise
16	Solar Panel PCB (fixed, 3cell)	2	FR4	Plate	85.80	80.0	146.0	1.6	No	-	Demise
17	Bottom cap	1	Aluminum 6061-T6	Box	83.40	100.0	100.0	10.0	No	-	Demise
18	532 nm Laser	1	Aluminum and FR4	Box	82.30	35	50.0	16	No	-	Demise
19	ISIS dipole Antenna	1	FR4	Box	80.00	100	100.0	7	No	-	Demise
20	Torque rods - Vertical	1	Copper and iron	Cylinder	75.00	17.2	22	17.2	Yes	2800°	Demise

21	NanoDock	1	FR4	Plate	66.30	10	10.0	1.6	No	-	Demise
22	Solar Panel PCB (fixed, 2cell)	2	FR4	Plate	64.00	79	99.0	1.6	No	-	Demise
23	Top cap	1	Aluminum 6061-T6	Box	62.70	100	100	10	No	-	Demise
24	Tether assembly	1	Aluminum 6061/PCB/Delrin	Box	60.20	50	86	40	No	-	Demise
25	532 receive lens tube	1	Hard Anodized Aluminum 6061-T6	Cylinder	55.80	30	85.0	30	No	-	Demise
26	Main breakout. PCB	1	FR4	Plate	54.40	10	10.0	1.6	No	-	Demise
27	Main Lidar Power Board	1	FR4	Plate	54.40	10	10.0	1.6	No	-	Demise
28	Main Lidar Processing Board	1	FR4	Plate	54.40	10	10.0	1.6	No	-	Demise
29	BBB Industrial	1	FR4	Plate	43.00	55	70.0	15	No	-	Demise
30	Novatel OEM719 GPS Receiver	**1**	FR4	Box	36.00	46	71.0	11	No	-	Demise
31	Tuna can antenna plate	1	Stainless steel	Plate	35.50	100	100	1	Yes	2500°	0 km
32	Solar Panel PCB (fixed, 2cell on target)	1	FR4	Plate	32.00	79.0	99.0	1.6	No	-	Demise
33	Tuna can mounting plate	1	Aluminum 6061-T6	Plate	30.20	100	100	2	No	-	Demise
34	AX100	1	Hard Anodized Aluminum 6061-T6 & FR4	Box	28.50	40	65.0	7.1	No	-	Demise
35	532 transmit lens tube	1	Hard Anodized Aluminum 6061-T6	Cylinder	27.60	15	85.0	15	No	-	Demise
36	Target inflatable	1	Mylar (BoPET)	Tetrahedron	25.85	816	1000.0	1000	No	-	Demise
37	GTRI experimental solar/capacitor panel	1	FR4	Plate	25.80	79	99.0	1.6	No	-	Demise
38	Lead screw & coupler	1	Stainless steel	Cylinder	17.00	3	150	3	Yes	2500°	0 km
39	fasteners	200	stainless steel	Cylinder	200.00	2	3	2	No	-	Demise
40	wire harnessing	200	teflon/kapton insulated threaded wire	Cylinder	200.00	0.1	80	0.1	No	-	Demise
41	helicoil inserts	80	stainless steel	Cylinder	80.00	2	3	2	Yes	2500°	Demise
42	Threaded tension rod - 15cm	8	Stainless steel	Cylinder	59.20	2	150	2	Yes	2500°	0 km
43	Tether motor	1	Stainless steel, copper	Cylinder	33.00	16	36	16	Yes	2500°	Demise
44	Torque Rod Brackets - Horizontal	4	Aluminum 6061-T6	Box	27.12	20	20	20	No	-	Demise

45	Transmit lens tube	1	Hard Anodized Aluminum 6061-T6	Cylinder	27.00	15	15.0	15	No	-	Demise
46	staking epoxy	1	3M Scotch Weld 2216 B/A Gray	Plate	25.00	50	50	2	No	-	Demise
47	GPS Patch Antenna	1	Ceramic	Plate	23.50	36	36	5	Yes	3720°	Demise
48	spacers	8	Alodined Aluminum 6061-T6	Cylinder	15.20	6	35	6	No	-	Demise
49	532 Rx mounting plate	1	Alodined Aluminum 6061-T6	Plate	14.50	48	69.0	3	No	-	Demise
50	Comparator Board	2	FR4	Plate	14.00	48	69.0	1.6	No	-	Demise
51	SolarMEMS Sun Sensor	2	Hard anodized Aluminum 6082 & FR4	Box	13.00	14	43.0	5.9	No	-	Demise
52	Solar panel hinges	4	Alodined Aluminum 6061-T6	Cylinder	12.28	4	30.0	4	No	-	Demise
53	532 lens tube to laser interface plate	1	Alodined Aluminum 6061-T6	Plate	11.40	35	50.0	3	No	-	Demise
54	Voxtel main board	1	FR4	Plate	11.10	**37**	48.0	5	No	-	Demise
55	Target valves	2	Stainless steel	Cylinder	11.00	3	10.0	3	Yes	2500°	Demise
56	Target electronics PCBs	1	FR4	Plate	10.15	51	58.0	25	No	-	Demise
57	Voxtel capacitor board	1	FR4	Plate	10.10	37	48.0	5	No	-	Demise
58	Pixycam2	1	FR4	Plate	10.00	38	42.0	15	No	-	Demise
59	EPSON M-G364 IMU	1	FR4	Box	10.00	24	24	10	No	-	Demise
60	CSS Rectangular PCB	3	FR4	Plate	9.85	23	44	1.6	No	-	Demise
61	Coarse Sun Sensor (CSS) Diode	4	Aluminum 6061-T6	Cylinder	9.00	12.5	12.5	10	No	-	Demise
62	1550 nm laser	1	Hard Anodized Aluminum 6061-T6 & FR4	Box	8.40	10	27.0	8	No	-	Demise
63	SiPM Board	1	FR4	Plate	7.00	48	69.0	1.6	No	-	Demise
64	Reaction Wheel Drive Control Electronics Board	3	FR4	Plate	6.50	33	33	1.6	No	-	Demise
65	532 laser assembly board spacers	12	Alodined Aluminum 6061-T6	Cylinder	6.00	4	4.0	3	No	-	Demise
66	Voxtel Detector	1	FR4 and optical glass	Plate	5.50	26	28.0	8	No	-	Demise
67	Torque Rod Brackets - Vertical	2	Aluminum 6061-T6	Box	5.28	20	20	20	No	-	Demise
68	thermal release switch	4	FR4	Plate	4.40	14.0	27.0	1.6	No	-	Demise

69	1550 nm laser mount	1	Alodined Aluminum 6061-T6	Plate	4.40	15	27.0	3	No	-	Demise
70	Magnetometer Circuit Board	1	FR4	Plate	4.17	10	10	1.6	No	-	Demise
71	Receiver lens tube	1	Hard Anodized Aluminum 6061-T6	Cylinder	3.80	*15*	30.0	15	No	-	Demise
72	PixyCam2 hinges	2	Alodined Aluminum 6061-T6	Cylinder	2.68	3	10	3	No	-	Demise
73	CSS Square PCB	1	FR4	Plate	2.52	32	32	1.6	No	-	Demise
74	532 nm laser transmit optic	1	Optical glass	Cylinder	2.00	12.5	12.5	3	No	-	Demise
75	532 nm receive optic	1	Optical glass	Cylinder	2.00	25	25.0	3	No	-	Demise
76	1550 nm laser transmit optic	1	optical glass	Cylinder	2.00	12.5	12.5	3	No	-	Demise
77	Flir Horizon Sensor	2	FR4	Plate	1.80	25	25.0	10	No	-	Demise
78	Tension rod coupler	1	Aluminum 6061-T6	Plate	1.36	10	10	3	No	-	-
79	Magnetometer	1	Permalloy	Plate	1.31	10	10	1.6	Yes	2650°	0 km