ELVL-2014-0043695 (Final)
March 14, 2014

Orbital Debris Assessment for The CubeSats on the NanoRacks / ELANA-8 Mission per NASA-STD 8719.14A

Signature Page

____

Justin Treptow, Analyst, NASA KSC VA-H1

____

Scott Higginbotham, Mission Manager, NASA KSC VA-C

____

Jason Crusan, Program Executive, NASA HQ SOMD

____

John Lyver, NASA HQ OSMA OD Manager

Signatures Required for Final Version of ODAR

____

Terrence W. Wilcutt, NASA Chief, Safety and Mission Assurance

____

William Gerstenmaier, NASA AA, Space Operation Mission Directorate

National Aeronautics and
Space Administration

John F. Kennedy Space Center, Florida
Kennedy Space Center, FL 32899

ELVL-2014-0043695

Reply to Attn of: VA-H1 March 14, 2014

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

FROM: Justin Treptow, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the ELANA-8 Mission (Final)

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6A, 5 February 2008
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14A, 25 May 2012
C. *Projected ISS Altitude Profile,* ISS Payload Planning Office, via email from Scott Higginbotham to Justin Treptow, 7 March 2014
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. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
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. *UL Standard for Safety for Household and Commercial Batteries, UL 2054*. UL Standard. 2nd ed. Northbrook, IL, Underwriters Laboratories, 2005

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELANA-8 auxiliary mission launching in conjunction with the CRS Orb-3 primary payload to the International Space Station. 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 NASA's Commercial Crew and Cargo Program and are not presented here.

The following table summarizes the compliance status of the ELANA-8 auxiliary payload mission flown on CRS Orb-3 flight. The CubeSat, ELANA-8 mission 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 0.7 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	No planned tether release under RACE mission

Section 1: Program Management and Mission Overview

The ELaNa-8 mission is sponsored by the Space Operations Mission Directorate at NASA Headquarters. The Program Executive is Jason Crusan. Responsible program/project manager and senior scientific and management personnel are as follows:

RACE: Boon Lim, Principle Investigator; Alexander Kadesch, Project Manager

Program Milestone Schedule	
Task	**Date**
CubeSat manifested	2/5/14
Pre-Ship Review	6/19/14 (U/R)
CubeSat Delivery to NanoRacks for Integration	7/3/14 (U/R)
Launch (CRS Orb-3)	10/3/14

Figure 1: Program Milestone Schedule

The ELANA-8 mission will deploy a pico-satellites (or CubeSats) as a secondary payload on the Orbital CRS Orb-3 mission.

The CubeSat is sized as 10 cm x 10cm x 30 cm, with mass of about 4.2 kg. The CubeSat has been designed and built by UT Austin and JPL.

The ELANA-8 mission will be launched from the International Space Station delivered by the CRS Orb-3 mission. The current launch date from the ISS, is in November or December of 2014 dependent on schedule**.** The CubeSat will be ejected from the NanoRack CubeSat Dispenser attached to the ISS Kibo module arm, placing the CubeSats in an orbit approximately 413 X 401 km at inclination of 51.6 deg (ref. (c)).

***RACE* CubeSat Description**

UT Austin / JPL – 3U

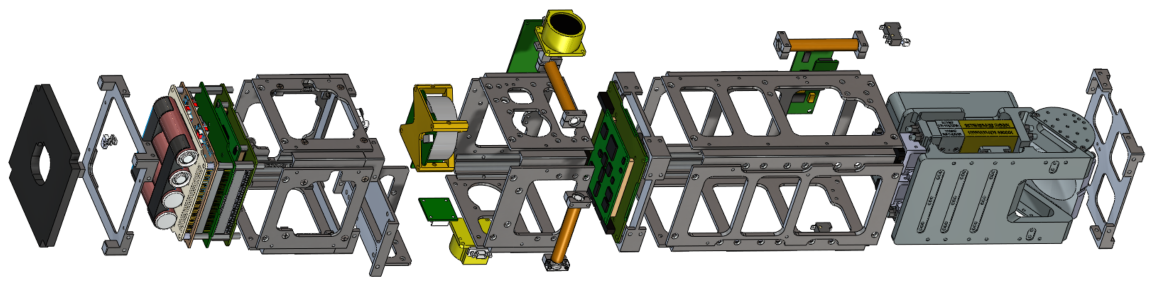

Figure 2: *RACE* Expanded View

The University of Texas at Austin's Texas Spacecraft Lab and Caltech are working in conjunction to develop a low cost Earth science satellite mission. Caltech is developing a 2-channel radiometer to measure the 183 GHz radio spectrum, while the TSL is designing, building, and operating a spin stabilized 3-unit CubeSat to carry the instrument.

The TSL will develop and operate a software defined ground station for satellite controlling and science data downlink. The TSL already holds a license for its on-campus ground station. The satellite will utilize the He-100 radio created by Astronautical Development, LLC for downlinking data critical to mission success. The ground station's software defined radios will be used to uplink telecommand to the spacecraft at 9600 bps, and downlink science data at 38400 bps.

Upon deployment from the NanoRacks launcher, the RACE satellite will wait 45 minutes to deploy antennas. Once communication with the UT-Austin ground station has been established and all flight systems checked, the spacecraft will detumble. Once the rotation rates are all within +/- 1 degree per second, the spacecraft will begin to spinup about it's z-axis, and orient the z-axis normal to the orbit plane. Once this attitude has been achieved, the radiometer instrument will begin taking measurements of the Earth's atmosphere. This data will be periodically downlinked along with attitude, position, and health telemetry, until a total of 50 hours of radiometer data has been sent to the ground station.

The primary CubeSat structure is made of *6061-T6 aluminum*. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

There are no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of common lithium-ion 18650 cell batteries with over-charge/current protection circuitry. They are the GOMSpace, ApS NanoPower BP4 battery pack.

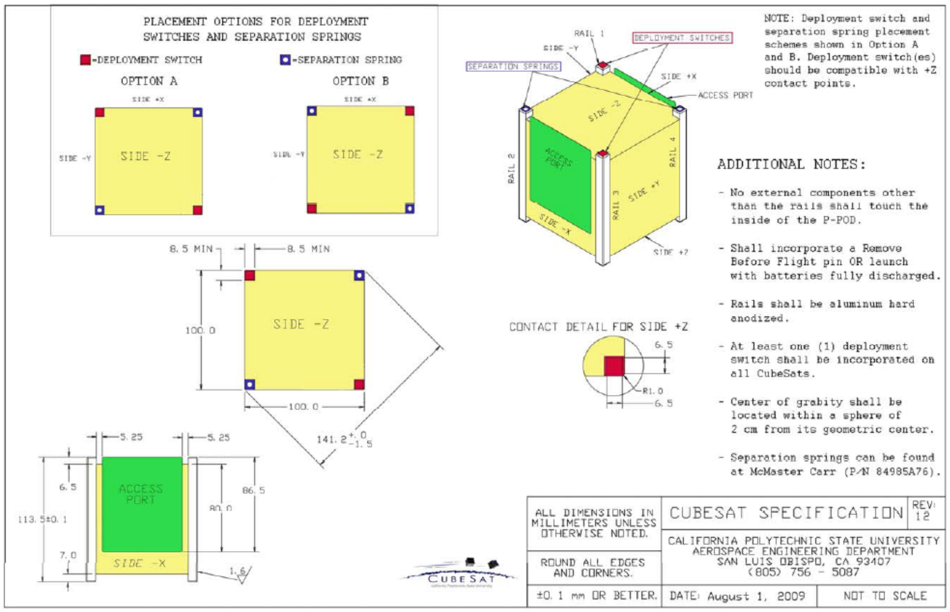

Figure 3: 1U CubeSat Specification

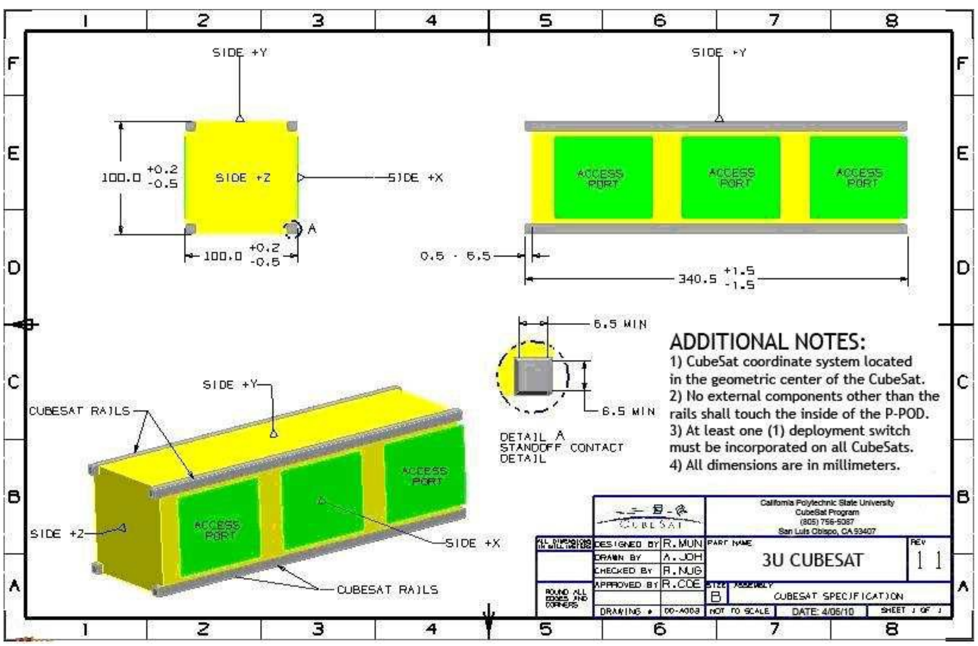

Figure 4: 3U CubeSat Specification

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.

No releases are planned on the RACE CubeSat mission therefore this section is not applicable.

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

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the ELANA-8 mission. No passivation of components is planned at the End of Mission for the RACE CubeSat.

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))

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a lifetime of 0.7 years maximum the ELANA-8 CubeSat is 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.

The largest mean cross sectional area (CSA) is that of the deployed configuration with antennas and extended (10 X 10 X 30 cm with two deployable antenna 0.3 X 50 cm and two deployable antennas 0.3 X 25cm):

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

Equation 2: Mean Cross Sectional Area for Complex Objects

All CubeSats evaluated for this ODAR are stowed in a convex configuration, indicating there are no elements of the CubeSats obscuring another element of the same CubeSats from view. Thus, mean CSA for all stowed CubeSats was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the P-POD and deployables have been extended Equation 2 is utilized to determine the mean CSA. A_{max} is identified as the view that yields the maximum cross-sectional area. A_1 and A_2 are the two cross-sectional areas orthogonal to A_{max}. Refer to Appendix A for dimensions used in these calculations

The ELANA-8 orbit at deployment is 413 km apogee altitude by 401 km perigee altitude, with an inclination of 51.6 degrees. With an area to mass (4.258 kg) ratio of 0.0104 m^2/kg, DAS yields 0.7 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. Even with the variation in CubeSat design and orbital lifetime ELANA-8 CubeSat sees an average of 10^{-8} probability of collision. The deployed configuration sees the highest probability of collision of $10^{-7.97}$. Table 4 below provides complete results.

Table 2: CubeSat Orbital Lifetime & Collision Probability

CubeSat

	Mass (kg)	ELANA-8
Stowed	**Mean C/S Area (m^2)**	0.0443
	Area-to Mass (m^2/kg)	0.0104
	Orbital Lifetime (yrs)	0.7
	Probability of collision (10^X)	-8
Deployed	**Mean C/S Area (m^2)**	0.0454
	Area-to Mass (m^2/kg)	0.0107
	Orbital Lifetime (yrs)	0.6
	Probability of collision (10^X)	-7.97

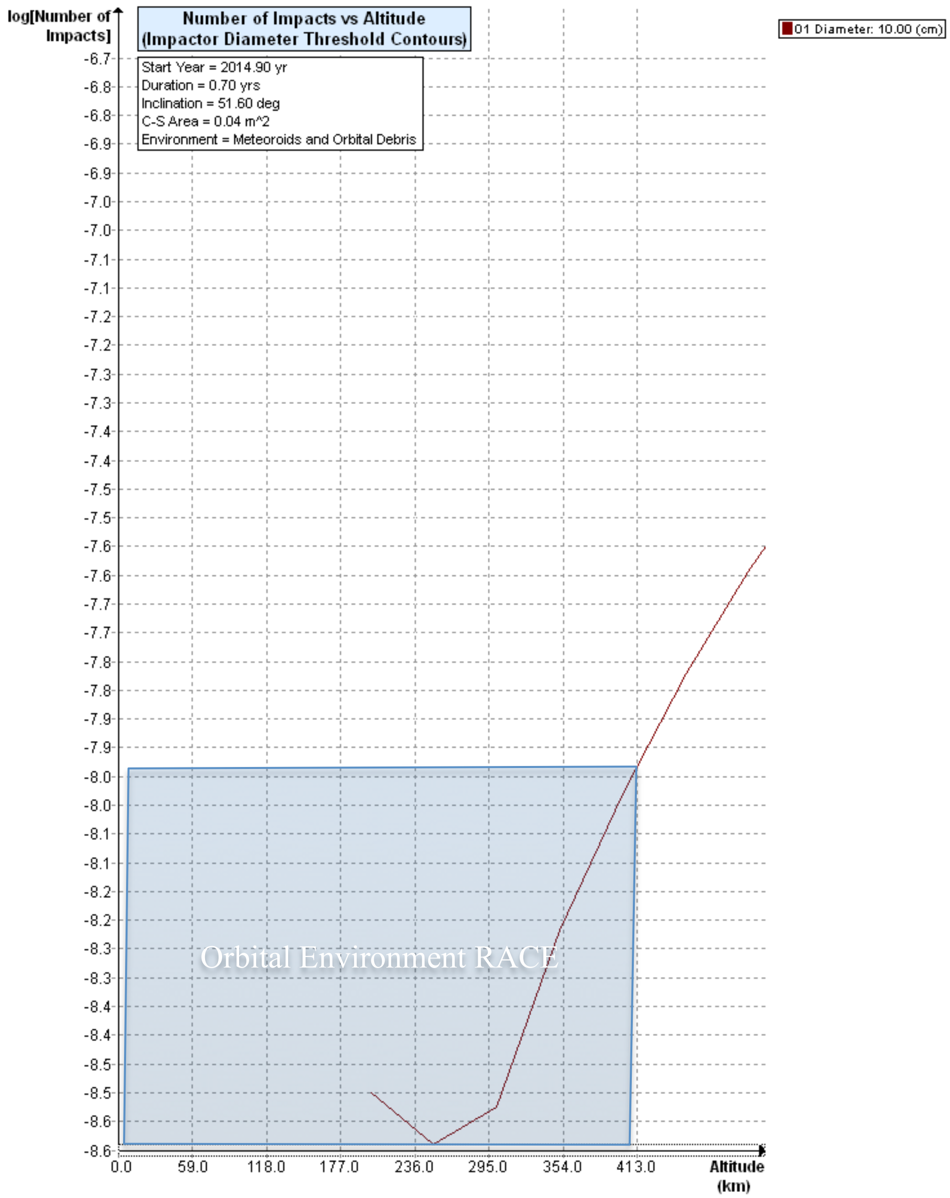

Figure 5: Highest Risk of Orbit Collision vs. Altitude (ELANA-8-Deployed)

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.

The probability of the ELANA-8 spacecraft collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than $10^{-7.95}$, for either configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Since the CubeSat have no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

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

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The RACE spacecraft 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 postmission 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 finds RACE in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

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

Equation 3: Area to Mass

$$\frac{0.0443m^2}{4.258\,kg} = \ 0.0104\frac{m^2}{kg}$$

The RACE stowed configuration has the smallest Area-to-Mass ratio and as a result will have the longest orbital lifetime. The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS 2.0.2 Orbital Lifetime Calculations:</u>

DAS inputs are: 401 km maximum perigee 413 km maximum apogee altitudes with an inclination of 51.6 degrees at deployment in November of 2014. An area to mass ratio of 0.0107 m^2/kg for the RACE CubeSat was imputed. DAS 2.0.2 yields a 0.7 years orbit lifetime for 0.6 in its stowed state.

This meets requirement 4.6-1.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on RACE was performed. The assessment used DAS 2.0, 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 can be expected to posses the same negligible risk as stainless steel components. See Table 3.

Table 3: RACE Stainless Steel DAS Analysis

CubeSat	ELaNa-4 Stainless Steel Components	Mass (g)	Length / Diameter (cm)	Width (cm)	Height (cm)		Demise Alt (km)	KE (J)	Pc
RACE	Reaction Wheel	123	5	5	2.95		0	63	1:146800

The majority of stainless steel components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have 63J kinetic energy with a probability of human casualty of 1:146,800, far below the requirement of 1:10,000.

Through the method described above, Table 3: RACE Stainless Steel DAS Analysis, and the full component lists in the Appendix the RACE CubeSat launching CRS Orb-3 mission are conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

See the Appendix for a complete accounting of the survivability of all CubeSat components.

Section 8: Assessment for Tether Missions

RACE CubeSat will not be deploying any tethers.

RACE CubeSat satisfy Section 8's requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 for the launch vehicle are addressed in ref. (g), and are not covered here.

If you have any questions, please contact the undersigned at 321-867-2958.

/original signed by/

Justin Treptow
Flight Design Analyst
NASA/KSC/VA-H1

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-G2/Mr. Atkinson
VA-G2/Mr. Fineberg
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos
VA-C Scott Higginbotham

Appendix Index:

Appendix A. Component List: RACE

Row Number	Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temp	Melting Temp (°C)	Comment
1	RACE 3U CubeSat		1									
2	CubeSat Structure	External - Major	1	Aluminum 6061-T6511	shelled box (2.5 mm thick)	1170	113.5	113.5	340.5	Yes		
3	Antennae System	External - Major	4	Aluminum, FR4 PCB, flex PCB	box	86	98	98	5.8	Yes		
4	Solar Panels (long)	External - Major	4	Germanium, glass, FR4 PCB, copper	sheet	512	83	340.5	2.4	Yes		
5	Solar Panels (short)	External - Major	5	Germanium, glass, FR4 PCB, copper	sheet	63	98	98	1.6	Yes		
6	Separation Switches	External - Minor	5	Thermoplastic acetal, copper, steel, silver plated bronze	box	42.5	20	12	6.5	Yes		
7	Sun Sensors	External - Major	2	Aluminum, copper	box	66.5	32	34	20	Yes		
8	Batteries	Internal - Major	4	Lithium-ion, FR4 PCB, aluminum	box	240	94	88	20	yes		
9	EPS Board	Internal - Major	1	FR4 PCB, copper, various electronic components	box	90	94	88	15	Yes		
10	Magnetic Torque Rods	Internal - Major	3	Copper wire, magnetic alloy rod	cylinder	81.5	10	70	-	yes		
11	Reaction Wheel	Internal - Major	1	Aluminum, Nitronic, Acetal, Samarium Cobalt, Stainless Steel	box	123	50	50	29.5	No	1480	63J of energy on reentry, Probability of Casualty 1:146800 See Table 3
12	Magnetometor	Internal - Major	1	FR4 PCB, copper, various electronic components	box	23.5	75	30.5	13	Yes		
13	Gyroscopes	Internal - Major	3	FR4 PCB, copper, various electronic components	box	7.5	25	25	6.5	Yes		
14	Payload Power Board	Internal - Major	1	FR4 PCB, copper, various electronic components	box	15	71	28	13.5	Yes		
15	UHF/VHF Radio	Internal - Major	1	FR4 PCB, copper, aluminum, various electronic components	box	68	94	88	13	Yes		
16	phyCORE-LPC3250	Internal - Major	2	FR4 PCB, copper, various electronic components	box	30	70	58	8.5	Yes		

Row Number	Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temp	Melting Temp (°C)	Comment
17	Kesler Interface Board	Internal - Major	1	FR4 PCB, copper, various electronic components	box	60	94	88	15	Yes		
18	Horton Interface Board	Internal - Major		FR4 PCB, copper, various electronic components	box	10	65	57	12	Yes		
19	Kraken Interface Board	Internal - Major	1	FR4 PCB, copper, various electronic components	box	60	94	88	15	Yes		
20	Hudson Interface Board	Internal - Minor	1	FR4 PCB, copper, various electronic components	box	10	65	57	12	Yes		
21	Radiometer Payload	Internal - Major	1	Aluminum, copper, teflon, various electronic components	box	1200	162	90	90	Yes		
22	Fasteners	Internal - Minor	Many	Stainless steel	-	150	-	-	-	No	1500	Demise
23	Cabling	Internal - Minor	Many	Copper alloy	-	150	-	-	-	Yes		