Capella 5&6 Orbital Debris Assessment Report (ODAR)

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This report is presented in compliance with NASA-STD-8719.14, APPENDIX A.

Report Version: 1, 1/6/2021

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DAS Software Version Used In Analysis: v3.1

VERSION APPROVAL and/or FINAL APPROVAL:

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PREPARED BY:

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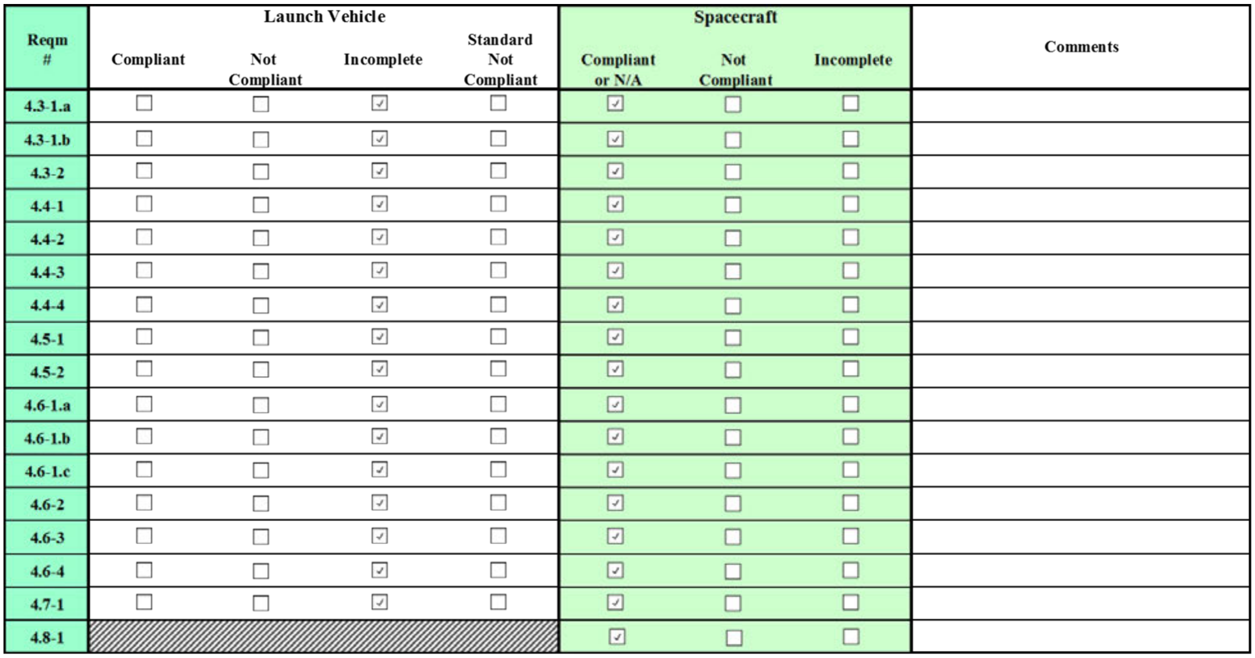
Self-assessment of the ODAR

This ODAR follows the format recommended in NASA-STD-8719.14, Appendix A.1, sections 1 through 8 for the Capella satellites. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

Orbital Debris Self-Assessment Report Evaluation: Capella Mission

(based upon ODAR version 1, dated January 6, 2021)



Reqm #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Not Compliant	Compliant or N/A	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☑	☐	☑	☐	☐	
4.3-1.b	☐	☐	☑	☐	☑	☐	☐	
4.3-2	☐	☐	☑	☐	☑	☐	☐	
4.4-1	☐	☐	☑	☐	☑	☐	☐	
4.4-2	☐	☐	☑	☐	☑	☐	☐	
4.4-3	☐	☐	☑	☐	☑	☐	☐	
4.4-4	☐	☐	☑	☐	☑	☐	☐	
4.5-1	☐	☐	☑	☐	☑	☐	☐	
4.5-2	☐	☐	☑	☐	☑	☐	☐	
4.6-1.a	☐	☐	☑	☐	☑	☐	☐	
4.6-1.b	☐	☐	☑	☐	☑	☐	☐	
4.6-1.c	☐	☐	☑	☐	☑	☐	☐	
4.6-2	☐	☐	☑	☐	☑	☐	☐	
4.6-3	☐	☐	☑	☐	☑	☐	☐	
4.6-4	☐	☐	☑	☐	☑	☐	☐	
4.7-1	☐	☐	☑	☐	☑	☐	☐	
4.8-1	▨	▨	▨	▨	☑	☐	☐	

Figure 1: ODAR Review Check sheet

1. Mission Overview

Project Manager: Duncan Eddy

Mission Overview: Capella 5&6 will be launched no earlier than April 2021, on a 53deg orbit at an altitude between 550km and 600km. For the purpose of this document, the worst case altitude in terms of lifetime of 600 km will be used.

ODAR Summary: All the debris generated in orbit are compliant with Requirements 4.3, there is no credible scenario for breakups, the collision probability with other objects is compliant with NASA standards, the estimated nominal decay lifetime due to atmospheric drag is less than 6 years (as calculated by DAS 3.1).

Launch: Capella 5&6 are currently planned to be launched on a SpaceX Falcon 9 rocket, no earlier than April 2021.

Mission Duration: Maximum Nominal Operations: 3 years, Post-Operations Orbit lifetime: less than 3 years until reentry via atmospheric orbital decay (worst case less than 6 years in total).

Orbit Profile: Capella 5&6 will deploy from the launch vehicle into a near-circular 53deg inclined orbit at an altitude of 575 km. They will maintain an altitude between 475 and 600 km using a RF xenon propulsion system for 3 years.

2. Spacecraft Description

Physical Description of the Spacecraft: Capella satellites have a launch mass between 100 kg and 120 kg. Two 500mm x 900mm deployable solar arrays, a 8 m^2 deployable antenna and a 3m long boom deploy from the principal bus structure.

All deployables use a frangibolt and motor based deployment system from which no debris will be generated.

Power storage is provided by Lithium-Ion cells. The batteries will be recharged by solar cells mounted on on the two deployable solar panels.

Capella attitude is estimated with an accuracy of 50 arcsec using filtering of sensor data from 2 star trackers, an IMU, sun sensors and a magnetometer. Capella attitude will be controlled by 3 reaction wheels for nominal operation and a 3-axis magnetorquer during detumbling and for wheel desaturation.

Total satellite mass at launch, including all propellants and fluids: 100 - 120 kg for all launches.

Dry mass of satellites at launch, excluding solid rocket motor propellants: 100 - 120 kg for all launches.

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): Capella 5&6 will be equipped with a propulsion system for station keeping. The baseline system is a xenon-based RF magnetic thruster from Phase Four. It is an electromagnetic electric propulsion system that accelerates the xenon propellant using magnetic mechanisms. It uses 1.1 kg of xenon for a maximum thrust force of 6 mN.

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: On Capella 5&6, the only fluid will be in the propulsion system tank. There will be 1.1 kg of xenon propellant. Xenon will be loaded onto the system to a target density which equates approximately 1,300 $psia$ at room temperature (25degC). The maximum operating pressure (MEOP) that the system will experience is 3,000 *psia* at 75degC assuming a full propellant load. The propulsion system can be filled with propellant either as a standalone system of while integrated into the satellite bus via external-facing fluid and electronic interface locations. Phase Four has designed and built ground support equipment to achieve the desired xenon density load. The design has been verified using the approach described in MIL-STD-1522A, approach B (page 28).

Fluids in Pressurized Batteries: None. Capella uses unpressurized standard Lithium-Ion battery cells. Each battery has a height of 65mm, a diameter of 18mm.

Description of attitude control system and indication of the nominal attitude of the spacecraft: Capella uses 3 magnetic rods to despin the satellites during the initial tumbling phase. 3 reaction wheels oriented in the direction of the principal axes allow 3-axis control during nominal operation. The magnetorquers are also used for desaturation of the wheels. The nominal attitude will be with the solar panels in the radial direction (R for radial) and the SAR antenna pointing in the nadir direction (-R). At the end of operations, the 3-axis controller can be used to rotate the satellite into maximum drag configuration, with the SAR antenna in the opposite direction of the velocity (-T for tangential), to accelerate orbital decay.

3. Spacecraft Debris Released during Normal Operations

Requirement 4.3-1: Debris passing through LEO, released debris with diameters of 1mm or larger

No release of debris will occur during the lifetime of Capella satellites. All deployments use a frangibolt and motor based systems that do not generate any debris. Additionally, there is no probable scenario for unintentional debris generation.

Result for Requirement 4.3-1: COMPLIANT

Requirement 4.3-2: Debris passing near GEO

There will be no intentional release of debris during the lifetime of the mission, as Capella's mission is contained in Low Earth Orbit.

Result for Requirement 4.3-2: COMPLIANT

4. Spacecraft Intentional Breakups and Potential for Explosions

Requirement 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

The probability of battery or pressurized tank explosion is very low, believed to be much less than 0.001 and, due to the small mass of the satellite and its short orbital lifetime, the long-term effects of an unlikely explosion on the LEO environment are negligible. During the development process, the heat pipes have been space qualified through pressure testing, burst pressure testing, vibration testing and thermal vacuum cycling. At the end of the 3 years of nominal operations, any leftover propellant can be used to accelerate the reentry of the satellite.

Failure mode 1: Internal short circuit.

Mitigation 1: Qualification and acceptance shock, vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge will prove that no internal short circuit sensitivity exists.

Combined faults required for realized failure: Environmental testing AND functional charge / discharge tests must both be ineffective in discovery of the failure mode.

Failure mode 2: Internal thermal rise due to high load discharge rate.

Mitigation 2: Cells will be tested in lab for high load discharge rates in a variety of flight like configurations to determine if the feasibility of an out of control thermal rise in the cell. Cells will also be tested in a hot environment to test the upper limit of the cells capability.

Combined faults required for realized failure: Spacecraft thermal design must be incorrect

AND external over current detection and disconnect function must fail to enable this failure mode.

Failure mode 3: Excessive discharge rate or short circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).
Mitigation 3: This failure mode will be negated by a) qualification tested short circuit protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, c) obviation of such other mechanical failures by proto-qualification and acceptance environmental tests (shock, vibration, thermal cycling, and thermal-vacuum tests).
Combined faults required for realized failure: An external load must fail/short-circuit AND external over-current detection and disconnect function must all occur to enable this failure mode.

Failure mode 4: Inoperable vents.
Mitigation 4: Battery vents are not inhibited by the battery holder design or the spacecraft.
Combined faults required for realized failure: The manufacturer fails to install proper venting.

Failure mode 5: Crushing.
Mitigation 5: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries.
Combined faults required for realized failure: A catastrophic failure must occur in an external system AND the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit AND the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.
Mitigation 6: These modes are negated by a) battery holder/case design made of non-conductive plastic, and b) operation in vacuum such that no moisture can affect insulators.
Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators AND dislocation of battery packs AND failure of battery terminal insulators AND failure to detect such failures in environmental tests must occur to result in this failure mode.

Failure mode 7: Excess temperatures due to orbital environment and high discharge combined.
Mitigation 7: The spacecraft thermal design will negate this possibility. Thermal rise will be analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions.
Combined faults required for realized failure: Thermal analysis AND thermal design AND mission simulations in thermal-vacuum chamber testing AND over-current monitoring and control must all fail for this failure mode to occur.

Result for Requirement 4.4-1: COMPLIANT

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon

Passivation will happen naturally at the end of mission by depletion of any remaining energy contained in the batteries (either through uncontrolled tumbling in case of ADCS failure or attitude control in case of nominal ADCS operations) and natural orbit decay and re-entry within 6 years.

Result for Requirement 4.4-2: COMPLIANT

Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups

There are no planned breakup during the mission.

Result for Requirement 4.4-3: COMPLIANT

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups

There are no planned breakup during the mission.

Result for Requirement 4.4-4: COMPLIANT

5. Spacecraft Potential for On-Orbit Collisions

Since the orientation of the spacecraft during operations will vary, the probability of collision with other objects is computed in the worst case scenario of the SAR antenna being in the direction tangential to the velocity. DAS v3.1 is used for orbit and collision analysis. It is to be noted that Capella's on-orbit collision avoidance scheme has already been implemented and TESTED SUCCESSFULLY on orbit.

Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit

The worst case initial orbit of Capella 5&6 is a circular orbit at an altitude of 575 km and an inclination of 53deg. The aera/mass ratio of the spacecraft is 0.035 m^2/kg in the worst-case attitude. The computed probability of collision with large objects for the satellites is 6.2245e-5. The compounded probability of collision with a large object for the 2 satellites is 0.00012, below the maximum acceptable probability of 0.01.

Result for Requirement 4.5-1: COMPLIANT

Requirement 4.5-2. Limiting the probability of damage from small objects when operating in Earth or lunar orbit

The component critical for post-mission operations are the communication hardware, the attitude control system, the solar panels and the batteries. The results for each critical subsystem, for a Capella satellite, are given in the table below. The probability of damage from small objects for Capella 5&6 is computed to be 1.3163e-4.

The probability of damage from small objects for the 2 satellites is 0.00026, below the 0.01 requirement.

Table 1: Small Object Damage Analysis for Capella 5&6

Critical Surface	**Probability of Penetration**
ADCS	9.8273e-6
COMS	4.9137e-6
Solar Panels	1.1435-4
Batteries	2.5413e-6
Probability of PMD Failure	**1.3163e-4**

Result for Requirement 4.5-2: COMPLIANT

6. Spacecraft Post-mission Disposal Plans and Procedures

The orbit of the satellite will decay because of atmospheric drag and the satellites will eventually naturally de-orbit by atmospheric reentry. At the end of the spacecraft lifetime, Capella will begin the deorbit process. At the end of the mission operations, Capella will use the attitude control system to orient the satellites into a maximum drag configuration with the solar panels and SAR antenna in the direction of the velocity, accelerating the orbital decay. These high-drag periods will be interleaved with sun-pointing periods to ensure spacecraft reserve power is maintained throughout the deorbit process. Capella will maintain enough fuel in the propulsion system to maintain maneuverability as the spacecraft passes through the ISS and Tiangong-2 orbits. In the case where there propellant in excess of what is needed to safely traverse the space station orbits it will be used in a series of propulsive maneuvers to further accelerate orbital decay and reentry. Even in the case of ADCS failure and tumbling spacecraft at end of life, all Capella satellites will de-orbit well within the maximum allowable 6 year lifetime. This analysis is assuming a worst-case scenario, for lifetime purposes, of a tumbling spacecraft.

Requirement 4.6-1. Disposal for space structures in or passing through LEO

The altitude of the satellite is computed from its worst case initial circular orbits at the altitude of 600 km, in its end of mission configuration. The average area to mass ratio for the tumbling spacecraft is used (0.035 m^2/kg). If the spacecraft is deployed at 600 km, no orbit maintenance will be performed to let the spacecraft deorbit faster. The lifetime of Capella 5&6 with no orbit maintenance is computed by DAS to be 2.4 years. If the spacecraft is deployed at 575 km, Capella can perform 3 years of orbit maintenance, after which the spacecraft will deorbit within 2.3 years, for a maximum lifetime of 5.3 years.

Result for Requirement 4.6-1: COMPLIANT

Requirement 4.6-2. Disposal for space structures near GEO

There are no space structures near GEO involved in this mission.

Result for Requirement 4.6-2: COMPLIANT

Requirement 4.6-3. Disposal for space structures between LEO and GEO

There are no space structures between LEO and GEO involved in this mission.

Result for Requirement 4.6-3: COMPLIANT

Requirement 4.6-4. Reliability of post-mission disposal operations in Earth orbit

The above analysis has been performed with an average area to mass ratio, which means that even in the case of massive power or ADCS failure, a tumbling spacecraft, the spacecrafts will deorbit in a worst case of 6 years.

Result for Requirement 4.6-4: COMPLIANT

7. Spacecraft Reentry Debris Casualty Risks

Requirement 4.7-1. Limit the risk of human casualty

The risk of human casualty was computed by DAS v3.1 for an uncontrolled reentry to be 1:100000000 for Capella 5&6. This is the lowest output of the DAS software. Considering 0 energy makes it to the ground during reentry, the risk of human casualty is effectively 0. The spacecraft models and results are summarized in the tables below.

Table 2: Spacecraft Model

Component	**Subcomponent**
Bus	
	Batteries
	Reaction Wheels
	Avionics
	Propulsion Tanks
	Radio Stack 1
	Radio Stack 2
SAR Antenna	
	SAR Antenna Battens
	SAR Antenna Hub
	Boom
	SAR Antenna Ribs
Solar Array	
Torque Rods	
Star Trackers	
Thruster	
Antennae	
Payload	

There are a number of carbon fiber epoxy components in the satellites. These components are being modelled in DAS using the default properties of Graphite Epoxy 1.

Table 3: Human Casualty Risk Analysis - Capella 5&6

Component	Qty	**Material**	**Shape**	**Mass (kg)**	**Dem. Alt. (km)**	**Cas. Area (m^2)**	**En. (J)**
Bus Structure	1	Aluminum	Box	28	61.4	0	0
Batteries	64	Aluminum	Cylinder	0.0625	76.3	0	0
Reaction Wheels	3	Aluminum	Cylinder	3.2	65.0	0	0
Avionics	1	Aluminum	Box	20.4	48.8	0	0
Tanks	1	Aluminum	Box	1.5	71.1	0	0
Radio Stack 1	1	Aluminum	Box	2.5	63.7	0	0
Radio Stack 2	1	Aluminum	Box	2.5	63.7	0	0
Ant Battens	13	Carb Fiber	Cylinder	0.4	77.7	0	0
Solar Array	2	Carb Fiber	Flat Plate	2.4	77.6	0	0
Torque Rods	3	Copper	Cylinder	0.6	73.4	0	0
Star Trackers	2	Aluminum	Box	0.3	74.9	0	0
Thruster	1	Aluminum	Box	2.5	63.7	0	0
Payload	1	Aluminum	Box	4	65.5	0	0
Boom	3	Carb Fiber	Cylinder	1.3	77.5	0	0
SAR Ant Ribs	13	Aluminum	Flat Plate	0.5	77.0	0	0
SAR Ant Hub	1	Aluminum	Box	5	58.9	0	0

Result for Requirement 4.7-1: COMPLIANT

8. Collision risk posed by tether systems

Requirement 4.8-1. Mitigate the collision hazards of space tethers in Earth or Lunar orbits

No tethers are to be used in Capella missions.

Result for Requirement 4.8-1: COMPLIANT

END OF ODAR FOR CAPELLA

Approved: Lucas Riggi
Constellation Architect
1/6/2021