Annex 2

QB50

Milieu-effectenstudie

(Environmental Impact Assessment)

-

ISS Launch
with OrbitalATK Inc. Antares 230 and the ISS procured through NanoRacks LLC

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PART I: ACTIVITIES AND OBJECTIVES

1. Objective of the activity and implementation through nanosatellites

The launch described in the present document (so-called *QB50 "ISS" launch*) has been procured by the von Karman Institute for Fluid Dynamics (VKI, Belgium) in the framework of the EU FP7 QB50 Project[1].

The QB50 mission aims to launch a network of (around) 50 nanosatellites (CubeSats) built by University Teams all over the world to perform first-class science in the largely unexplored lower thermosphere. More specifically, the constituents of the thermosphere will be measured by three types of scientific instruments carried by the CubeSats. Some CubeSats will also demonstrate new technology developments.

QB50 will make use of two different launch campaigns to complete the orbital injection of all the CubeSats, as shown in Table 1. Each of the campaigns will be the object of a request for authorization and of an environmental impact assessment. The present document reports on the ISS launch campaign.

Launch campaign	Launcher	Main objective	Number of CubeSats	Launch period
ISS	Antares (Orbital ATK) and ISS facilitated by Nanoracks	Scientific + technology demonstration	39 *(35 to be authorized by Belgium + 4 authorized and registered by the USA)*	February – July 2017
Polar	PSLV	Polar scientific measurement and In-Orbit Demonstration (IOD)	8	Q2-Q4 2017

Table 1 - Definition of the QB50 launch campaigns.

The ISS mission will focus on high-resolution scientific measurements of constituents of the thermosphere at low latitude between 200 - 380km altitude, which is the least explored layer of the atmosphere. To explore this region, atmospheric explorers were flown in the past in highly elliptical orbits (typically 200 km perigee, 3000 km apogee); they carried experiments for single-point, in-situ measurements but the time spent in the region of interest was only a few tens of minutes. By contrast, QB50 will provide multi-point, in-situ measurements for a time period on the order of months, instead of minutes.

Nowadays, sounding rocket flights provide the only in-situ measurements. While they do explore the whole lower thermosphere, the time spent in this region is rather short (a few minutes). There are only a few flights per year and they only provide measurements along a single column. Powerful remote-sensing instruments on board Earth observation satellites in higher orbits (600–800 km) receive the backscattered signals from atmospheric constituents at various altitudes. While this is an excellent tool for exploring the lower layers of the atmosphere up to about 100 km, it is not ideally suited for exploring the lower thermosphere because there the atmosphere is so rarefied that the return signal is weak. The same holds for remote-sensing observations from the ground with lidars and radars.

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[1] "QB50 : An international network of 50 CubeSats for multi-point, in-situ measurements in the lower thermosphere and re-entry research". EU FP7 Grant Agreement Number 284427

The multi-point, in-situ measurements of QB50 will be complementary to the remote-sensing observations by the instruments on Earth observation satellites and the in-situ measurements by sounding rockets. All atmospheric models, and ultimately thousands of users of these models, will benefit from the measurements obtained by QB50 in the lower thermosphere.

To this end, 35 double nanosatellites (35 "double CubeSats") of approximate dimensions 20x10x10cm and 4 triple nanosatellites (4 "triple CubeSats") of approximate dimensions 30x10x10cm are being built and launched. Figure 1 shows a double CubeSat. Almost all CubeSats will carry one instrument out of the 3 different QB50 instruments.[2]

The ISS campaign will also accommodate the reentry CubeSat Qarman that was built in Belgium by the von Karman Institute. QARMAN is designed to collect scientific data during its entry to Earth's atmosphere. Atmospheric entry and associated aerothermodynamics phenomena are considered as critical research topics for the safety of the spacecraft. The QARMAN Project aims at creating an affordable research platform to perform scientific studies in these fields.

Figure 1 – A double CubeSat (QB50p1 satellite).

The QB50 ISS launch (object of the present document) will take place using the Antares 230 rocket built and operated by Orbital ATK Inc. The launch base is located in Virginia, USA (see Figure 2).

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[2] Please note that amongst the 39 CubeSats for the ISS launch, only 35 have to be authorized by the Belgian state. Four CubeSats will be authorized and registered by the United States.

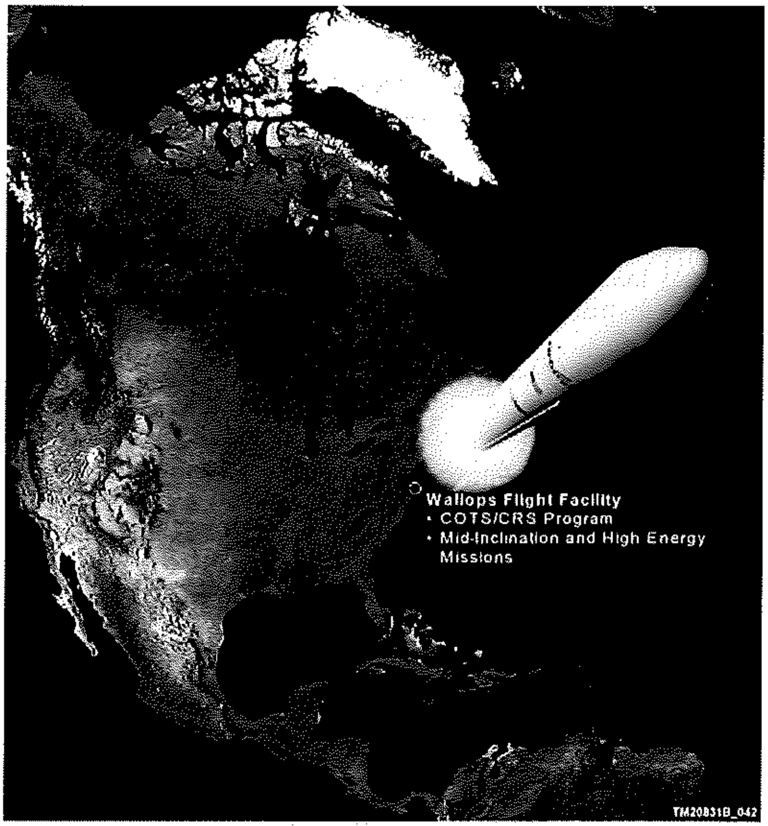

Figure 2 - Wallops Flight Facility

The QB50 CubeSats will be boarded as cargo in the Cygnus automated spacecraft. Cygnus is itself launched by the Antares rocket that delivers it to a 250 by 275 km orbit inclined 51.66 degrees 630 seconds after launch. From there, Cygnus begins orbit adjustments and phasing manoeuvres in order to dock with ISS that orbits Earth at an altitude of 410 km. After a few days, Cygnus is finally grabbed by the robotic arm and berthed to the International Space Station.

All along the process, CubeSats are stored in Nanoracks CubeSat Deployers (NRCSD). The NanoRacks CubeSat Deployer (NRCSD) is a self-contained CubeSat deployer system that mechanically and electrically isolates CubeSats from the ISS, cargo resupply vehicles, and ISS crew. For a deployment, NRCSD are attached to a platform, which is moved outside via the Kibo Module's Airlock and slide table that allows the Japanese Experimental Module Remote Manipulator System (JEMRMS) to move the deployers to the correct orientation for the satellite release and also provides command and control to the deployers. Each NRCSD is capable of holding six CubeSat Units (2 or 3 QB50 CubeSats).

Figure 3 shows CubeSats being deployed out of the NRCSD.

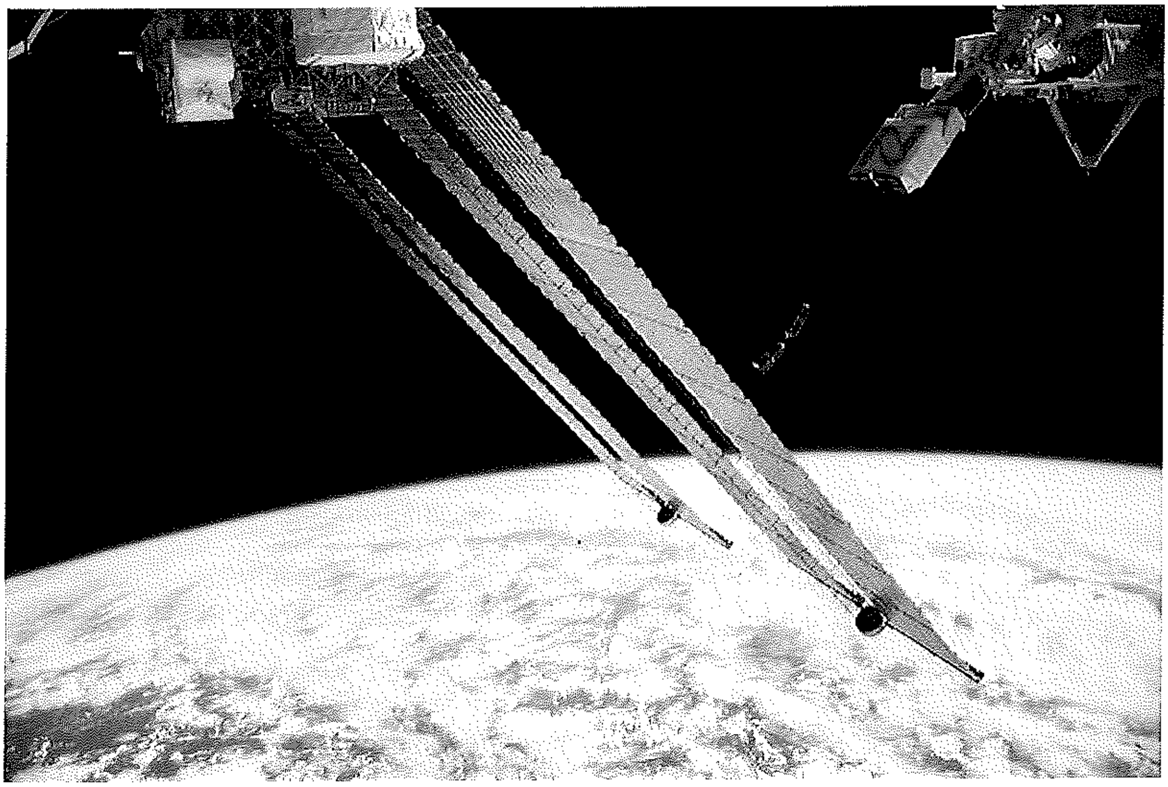

Figure 3 - CubeSats being deployed from the ISS.

The launch window for the Antares flight for the ISS campaign has been established from 1st February 2017 until 30th June 2017. The CubeSats will be deployed from the ISS in two batches: the first batch a few weeks after the Antares launch and the second batch 2-3 months later.

The launch is procured by VKI through Nanoracks LLC, which coordinates and takes care of all activities involving Orbital ATK and NASA.

2. Antares 230 launch vehicle

2.1. General overview

Antares is a two-stage vehicle (with optional third stage) that provides low-Earth orbit launch capability for payloads weighing up to 8,000 kg.

A general overview of the launch vehicle is shown in Figure 4.

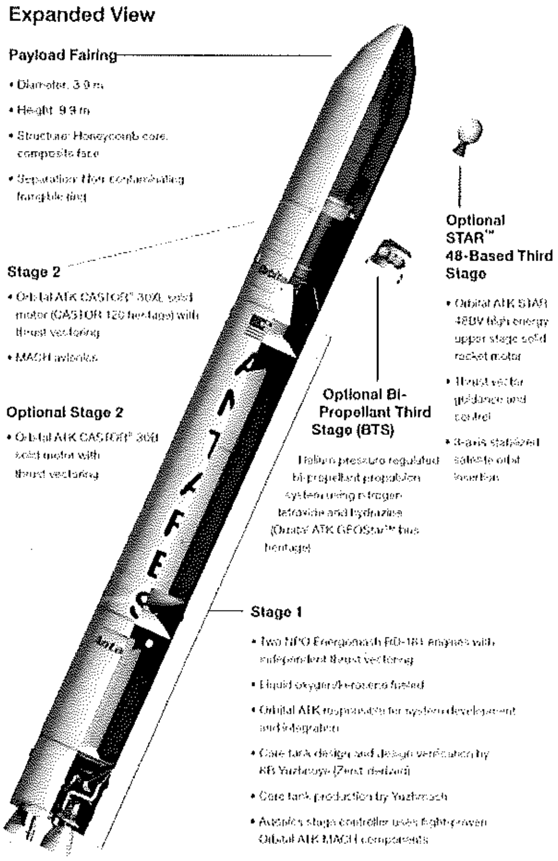

Figure 4 - Expanded view of Antares launch vehicle.

In the Antares 200 configuration, the launch vehicle first stage is powered by two RD-181 engines. They burn kerosene and liquid oxygen.

The second stage is an Orbital ATK Castor 30XL solid-fuel rocket.

The 3.9m fairing can accommodate large payloads, such as the Cygnus spacecraft.

Cygnus is an American automated cargo spacecraft developed by Orbital ATK. The QB50 CubeSats (loaded into their deployers) will be carried in the Pressurized Cargo Module of Cygnus.

2.2. Launcher quality controls

The Antares launch system utilizes Orbital ATK's proven MACH avionics system and many management approaches, engineering standards, production and test processes common to Orbital ATK's family of successful small-class Pegasus and Minotaur launch vehicles. The Antares design has been upgraded with newly-built RD-181 first stage engines to provide greater payload performance and increased reliability. The company will conduct five additional missions thru 2018 to fulfill the company's CRS1 agreement with NASA to deliver supplies to the ISS. Orbital ATK recently was awarded the CRS2 contract which includes at least six missions starting in 2019.

Antares features a low-risk design approach by incorporating flight proven components from leading global suppliers, and by utilizing subsystems design successfully flown on many Orbital launch vehicles[3].

2.2.1. Improvements of the quality level after CRS-3 launch failure (2014) (Ref. [4])

As a consequence of the Antares launch failure on October 28, 2014 (CRS-3 mission), where 15 seconds after lift-off an explosion of the Antares Main Engine System (MES) occurred, Orbital ATK established an Accident Investigation Board (AIB), consistently with the protocols approved by NASA and FAA, and in observance of the NASA Contingency Action Plan. Also representatives from the ISS Program were included as part of the Board. Almost in parallel, in November 2014, NASA (specifically the Associate Administrator for Human Exploration and Operations) established and IRD (Independent Review Team) with the specific scope to investigate independently the root causes of the launch failures. Among the main outcomes of the IRT report, there was the provision of "*recommendations on how to develop, operate and acquire more reliable systems*".

The IRT concluded on 6 Technical Findings (TFs) and seven Technical Recommendations (TRs): according to IRT position, *if fully implemented the TRs would likely resolve the technical root causes and prevent reoccurrence of a similar failure in the systems*".

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[3] Antares OSP-3 Users's guide, release 1.1, July 2013

[4] NASA Independent Review Team Orb-3 Accident Investigation Report – executive summary, October 9th 2015, http://www.nasa.gov/sites/default/files/atoms/files/orb3_irt_execsumm_0.pdf

Technical Findings	
TF-1	The AJ26 LO2 turbopump thrust bearing and HBA have numerous intricacies and sensitivities that make it difficult to reliably manage the bearing loads and makes this area of the turbopump vulnerable to failure and oxygen fires.
TF-2	Given the non-linear rotordynamic behavior of the NK-33/AJ26 LO2 turbopump, life testing at the 2x Antares mission profile and duration was not sufficient to demonstrate bearing life margin.
TF-3	The instrumentation suite for the engines during flight and ATP was not sufficient to gain adequate insight into engine performance and to support anomaly investigation efforts.
TF-4	A comprehensive delta-qualification program for the AJ26 engine with the design changes and flight parameters planned for Antares missions was not performed.
TF-5	Although the IRT cannot definitively conclude that FOD was the cause or a contributor to the E15 failure, evidence suggests that FOD was present within E15 at the time of failure.
TF-6	Based on forensic inspection of E15 and E17, workmanship issues in E15 are credible contributors to the Orb-3 failure.

Technical Recommendations		**Finding(s) Addressed by Recommendation**
TR-1	NASA should not rely on the AJ26 for further missions without undertaking a more thorough inspection, qualification and acceptance test, and certification program.	TF-1, TF-2, TF-4, and TF-6
TR-2	For the new RD-181 engine that Orbital ATK has identified as a replacement to the AJ26 engine, Orbital ATK should ensure a thorough qualification program and acceptance test program is implemented specific to planned Antares operations.	TF-2 and TF-4 (Also, PF-7, PF-8)
TR-3	For future Antares missions, additional MES sensors and sensor filtering should be provided by Orbital ATK.	TF-3
TR-4	For future engine ATPs, sensors more suitable to the test environment should be utilized, and sensors should be better placed to understand and characterize engine performance.	TF-3
TR-5	Greater insight and verification activities should be implemented to ensure that cleanliness is consistent with engine (and other critical component) requirements.	TF-5
TR-6	To further reduce the likelihood of moisture intrusion into the engine, a more robust and verifiable moisture barrier approach should be utilized by Orbital ATK.	TF-5
TF-7	Orbital ATK and NASA should have greater insight into and understanding of engine design, certification, and operation.	TF-1, TF-2, TF-3, TF-4, TF-5, TF-6

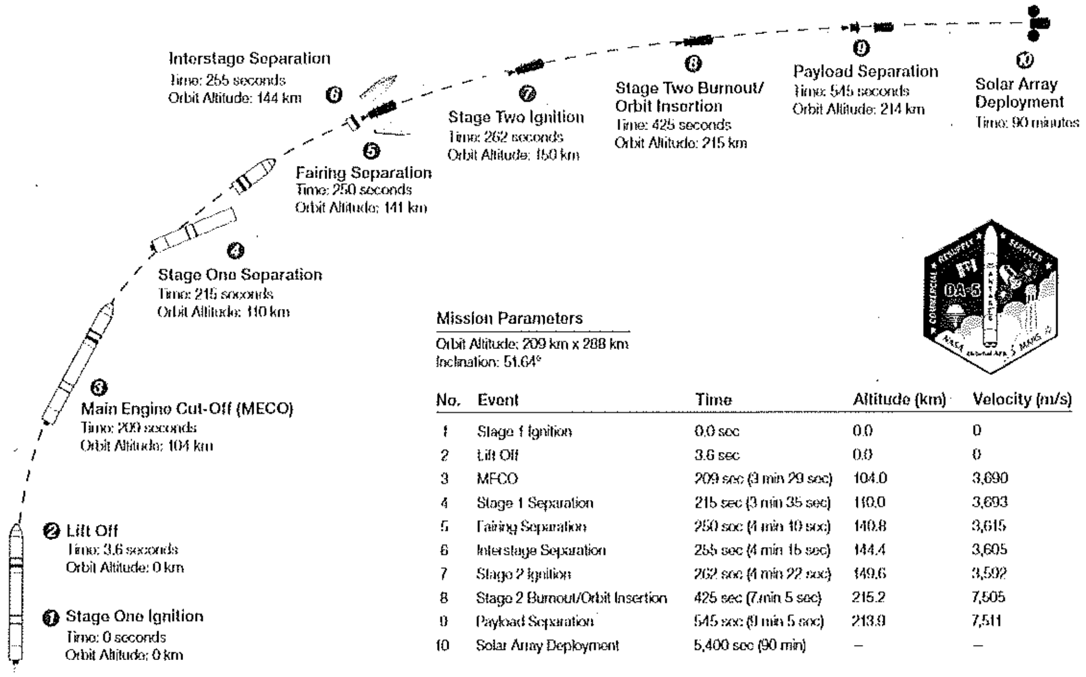
Table 2 - Technical Findings and Technical Recommendations from NASA IRT

In addition, orbital ATK was already procuring and testing new engines to replace the AJ26. The IRT provided also a number of additional recommendations that were used to support the test activities for risk reduction purposes, in view of the Antares' return to flight and follow-on missions.

On 17 October 2016 Orbital ATK restarted the Antares launches with the successful CRS-5 mission.

2.3. Antares mission profile

Figure 5 gives a detailed overview of the mission profile of the Antares 230 launch vehicle.



Mission Parameters

Orbit Altitude: 209 km x 288 km
Inclination: 51.64°

No.	Event	Time	Altitude (km)	Velocity (m/s)
1	Stage 1 Ignition	0.0 sec	0.0	0
2	Lift Off	3.6 sec	0.0	0
3	MECO	209 sec (3 min 29 sec)	104.0	3,690
4	Stage 1 Separation	215 sec (3 min 35 sec)	110.0	3,693
5	Fairing Separation	250 sec (4 min 10 sec)	140.8	3,615
6	Interstage Separation	255 sec (4 min 15 sec)	144.4	3,605
7	Stage 2 Ignition	262 sec (4 min 22 sec)	149.6	3,592
8	Stage 2 Burnout/Orbit Insertion	425 sec (7 min 5 sec)	215.2	7,505
9	Payload Separation	545 sec (9 min 5 sec)	213.9	7,511
10	Solar Array Deployment	5,400 sec (90 min)	–	–

Figure 5 - Mission Profile of Antares 230.

2.4. Antares launch vehicle performance characteristics

Figure 6 below gives an overview of the performance of the Antares launch vehicle for circular orbits at 38°, 51.6°, and SSO inclinations, both for 230 and 231 configurations. The payload mass the launch vehicle can carry for each of the aforementioned inclinations is mentioned. As mentioned before, the QB50 launch will take place with the 230 configuration.

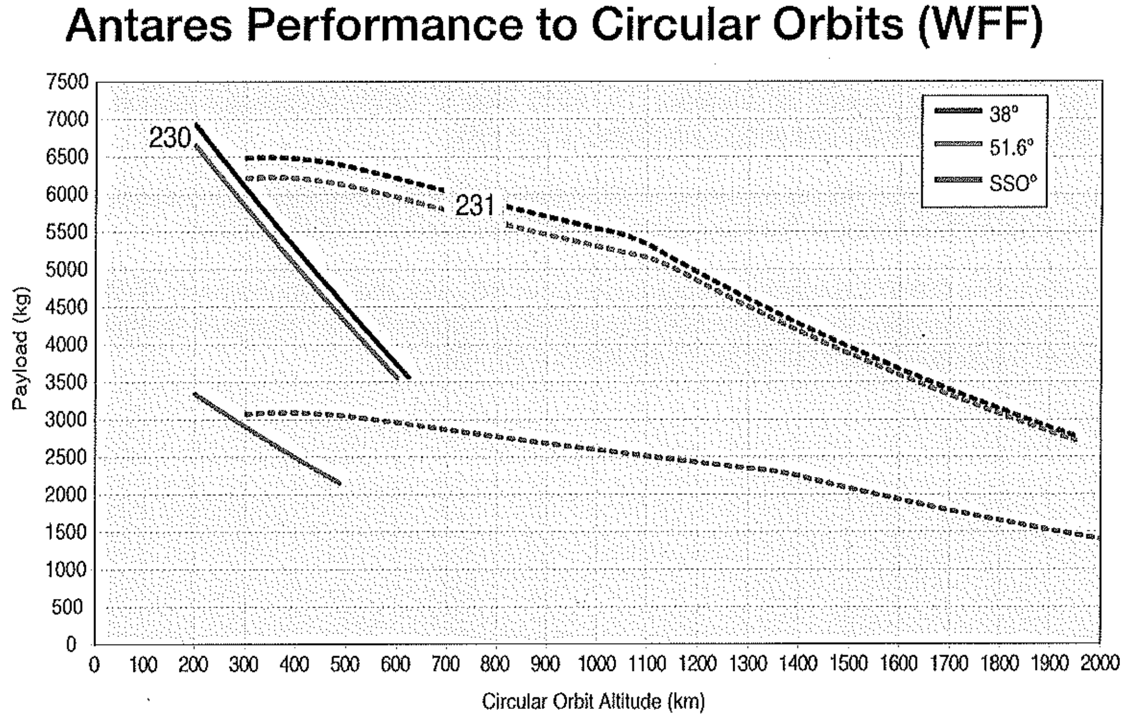


Figure 6 - Antares launch vehicle performances.

2.5. Launch and track record

Six launches of Antares took place to date. The first Antares was launched successfully in April 2013 in 110 configuration. It was followed by 3 successful launches in 110 (2nd launch) and 120 (3rd and 4th launches) configurations.

In October 2014, an Antares 130 launch failed. Fifteen seconds after liftoff a failure of propulsion occurred in the first stage. The vehicle began falling back to the launch pad and the Range Safety Officer engaged its flight termination system just before impact.

After that failure, Antares first stage has been upgraded with RD-181 engines. Antares was successfully launched in this 230 configuration on October 17, 2016. The same configuration will be used for QB50 launch.

Table 3 summarizes Antares mission history.

#	Launch Date	Configuration	Payload	Result
1	April 21, 2013	110	Cygnus Payload Simulator	Success
2	September 18, 2013	110	Cygnus (COTS Demonstration)	Success
3	January 9, 2014	120	Cygnus (CRS Mission #1)	Success
4	July 13, 2014	120	Cygnus (CRS Mission #2)	Success
5	October 28, 2014	130	Cygnus (CRS Mission #3)	Failure
6	October 17, 2016	230	Cygnus (CRS Mission #5)	Success

Table 3 - Antares mission history.

2.6. Conclusion

Antares rockets operated by Orbital ATK LSP are still part of the launch vehicles family supposed to provide on behalf of the ISS programs supplies to the International Space Station: the latest launch on October 17, 2016 was a 100% successful launch, providing supplies and payloads (including CubeSats) to the ISS.

The infamous launch failure occurred in 2014 have indeed contributed to increase the overall safety and further mitigate the risks associated to the execution of the launch.

Therefore the QB50 Consortium, coordinated by VKI, with the cooperation of NANORACKS LLC (service provider for the CubeSat deployment) considers the Antares a reliable rocket to achieve a successful upload of the CubeSats on the ISS.

PART II: POTENTIAL IMPACT OF THE ACTIVITIES ON THE TERRESTRIAL ENVIRONMENT, THE ATMOSPHERE AND THE NATURAL AND HUMAN ENVIRONMENT OF THE PLACE OF LAUNCHING

1. Acronyms

EA	Environmental Assessment
ELV	Expendable Launch Vehicle
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
GSFC	Goddard Space Flight Center
GHG	Greenhouse Gases
GWP	Global Warming Potential
HAZCOM	Hazard Communication
ICP	Integrated Contingency Plan
NASA	National Aeronautics and Space Administration
OB	Open Burn
OCST	Office of Commercial Space Transportation
USCG	U.S. Coast Guard
USDOT	Department of Transportation
USFWS	U.S. Fish and Wildlife Service
WFF	Wallops Flight Facility

2. Introduction

This document is an extract of the *Site-Wide Environmental Assessment of Wallops Flight Facility, Virginia* (January 2005, ERS Group, Inc. and EG&G Technical Services for NASA) and *Final Supplemental Assessment Antares 200 Configuration Expendable Launch Vehicle at Wallops Flight Facility* (NASA, FAA OCST).

3. Affected Environment

The analysis of the conditions of the resources potentially affected together with the discussion of impacts in proportion to their significance is reported in this chapter.

The affected environment includes Wallops Island, the nearshore zone over which surveillance aircraft and the Antares ELV would fly, and the offshore areas within which the Antares ELV would jettison its flight hardware.

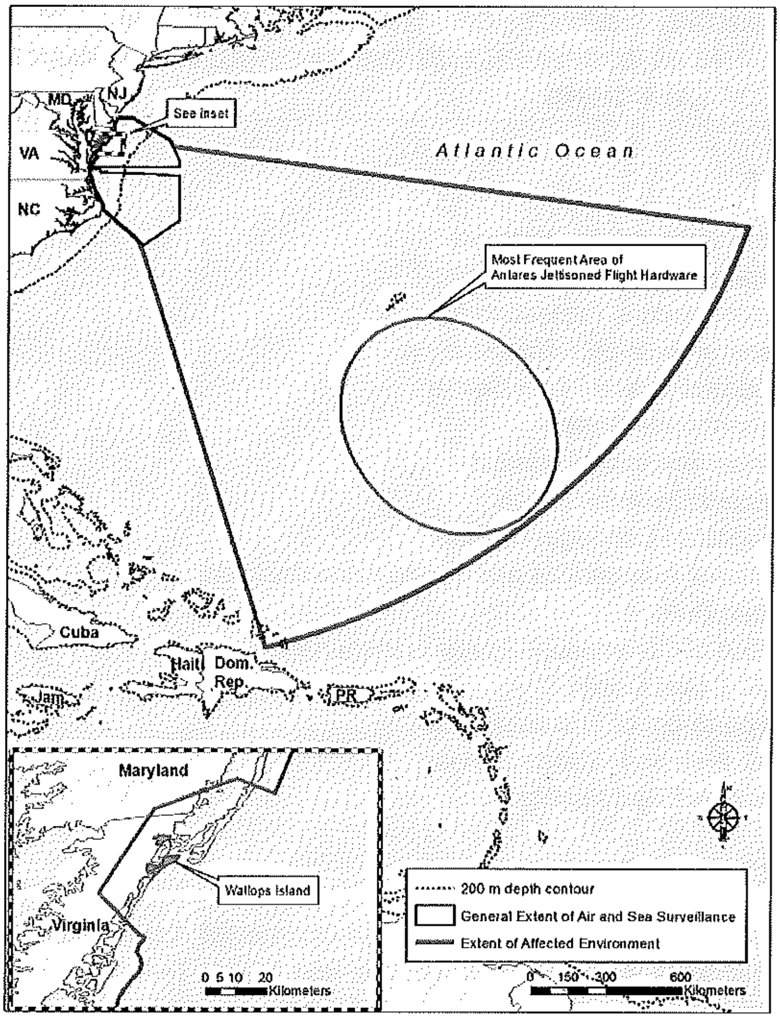


Figure 7 : Extent of Affected Environment Considered

4. Physical Environment

4.1. Land Resources

Geology and Soil

In general, existing and proposed operations are not expected to significantly impact soils at WFF. All activities take place at or adjacent to impervious surfaces (i.e., concrete, tarmac, asphalt). Also, existing WFF policies are in place to ensure the safe storage, transfer, and mixing of hazardous materials. Any accidental release of liquid fuels would be addressed in accordance with existing management and response plans, and are not expected to significantly impact soil resources. However, there is some potential for the release of contaminants into the soil resulting from routine maintenance and fueling activities or an accident that releases liquid fuels to a non-impervious surface.

Atlantic Ocean Substrate

Rockets

Rocket motors present a potential source of pollution to marine sediments. However, toxic concentrations of metal ions are not produced because the corrosion rates are slow in comparison to the mixing and dilution rates associated with marine environments. Also, metal ions do not adhere to the sandy substrate of the Atlantic Ocean; therefore, no negative impact to the substrate is anticipated (NASA, 2003a).

In the event of a launch failure, debris from reentered hardware could impact the ocean much closer to shore than would occur with a successful launch, and could result in more substantive impacts. However, the probability of such an event is extremely small (estimated at 1 percent probability); therefore, such an event should not pose a significant environmental impact (NASA, 1997a).

Payloads

Payloads have the potential to affect marine sediments when they come to rest on the ocean floor and begin to release metal ions. As mentioned above, however, toxic concentrations of metal ions are not produced because the corrosion rates are slow in comparison to the mixing and dilution rates associated with marine environments and metal ions do not adhere to the sandy substrate of the Atlantic Ocean; therefore, no negative impact to the substrate is anticipated (NASA, 2003a). Payloads may contain batteries, which have the potential to affect marine sediments when they come to rest on the ocean floor. However, battery constituent concentrations have been found to represent a less than significant impact on marine sediment quality for each target event. In terms of long-term accumulation of contaminants in marine sediments, the impact from battery constituent concentrations is considered less than significant because it is highly unlikely that the same area of marine sediment would be affected more than once in a given year (NASA, 2003a).

4.2. Water Resources

Surface Water

The accidental release of hazardous materials, including fuels, from operational activities or from an accident could impact water resources at WFF by contaminating surface waters. WFF has developed and implemented an Integrated Contingency Plan (ICP) to minimize hazards to human health and the environment that could occur as the result of an accidental release of hazardous materials. The ICP identifies the locations of hazardous material storage areas and outlines spill prevention, control, response, and remediation procedures, and training protocols for personnel who work with hazardous materials (NASA, 2001c). Strict compliance with the ICP should minimize the risk of accidental releases of hazardous materials that could impact surface waters and minimize impacts to surface waters should an accidental release occur.

Rockets

All rocket launches at WFF are from the beach and directed toward the ocean. Consequently, the impacts on surface waters at WFF are minimal and are limited to the launch pad area. Chemical compounds emitted as part of solid propellant launch rocket exhausts include hydrogen chloride gas, water vapor, and aluminum oxide particles. It is likely that stormwater runoff would collect aluminum oxide particulates that settle on the pad following a launch. Aluminum oxide is not listed by the EPA as a hazardous substance that requires special treatment or disposal. Numerous NASA studies have evaluated the hydrogen chloride-aluminum oxide scavenging process. Aluminum oxide particulates are known to gather water vapor and hydrogen chloride gas to form acidic droplets in the immediate vicinity of the pad. Should a storm event occur soon after a launch event, the potential for strongly acidic stormwater runoff from the pad area exists. However, since launches are not undertaken under potentially adverse weather conditions, the chance of a storm event very soon after a launch are small.

Any surface water in the vicinity of the launch pad may incur a short-term increase in acidity as a result of localized emission cloud formation. The salinity of estuarine and ocean waters would buffer acidity changes in such water bodies. From an environmental perspective, Launch Complex 0 is the most sensitive launch area on Wallops Island. Launch Complex 0, which includes both Pad 0-A and 0-B, lies between the Atlantic Ocean and Hog Creek on the southern end of the island and would be used for launching orbital rockets. Launch Pad 0-B is equipped with a flame duct to direct the flame toward the Atlantic Ocean, which should help minimize impacts to the marshland and Hog Creek, west of the pad. Due to the proximity of these bodies of water, the pH of nearby surface waters may slightly decrease for 1 to 2 hours after a rocket launch; however, changes in water quality should be negligible due to the rapid buffering capacity of estuarine waters. A nominal launch would have no substantial impacts to the local water quality (NASA, 2000a). Rocket motors burned at the OB area are the same as those that are launched. The only difference is that during a burn, the motor is strapped in one place and all deposition occurs immediately surrounding the OB area versus along a launch trajectory. Therefore, a burn would likely result in a greater impact than a launch. To analyze impacts from OB activities, the WFF Environmental Office has performed surface water quality checks of the wetlands surrounding the OB area both prior to and after an open burn event. Over three sampling events, pH in the wetlands decreased an average of 0.1 with a standard deviation of 0.4. No decrease in pH was noted in the Atlantic Ocean. Therefore, no impacts are anticipated from acid deposition during a launch.

Stormwater

Rockets

Stormwater runoff from WFF launch pads may contain aluminum oxide particles that have accumulated from the launch of solid rocket motors. Aluminum oxide is not classified as a hazardous substance by the Environmental Protection Agency (EPA), but aluminum oxide particles have been known to accumulate water vapor and hydrogen chloride gas to form acidic droplets. In the event a storm occurs immediately following a launch, the potential for runoff with a low pH may exist. However, due to the potential of lightning strikes, the launching of vehicles would not occur under adverse weather conditions, thus reducing the probability of a storm event and runoff immediately following a launch.

Marine Waters

The accidental release of hazardous materials, including fuels, from operational activities or an accident could impact water resources at WFF by contaminating marine waters. Strict compliance with the ICP should minimize the risk of accidental releases of hazardous materials that could impact marine waters and minimize impacts to marine waters should an accidental release occur.

Rockets

Corrosion of jettisoned or reentered hardware is a potential source of pollution to the marine environment; however, toxic concentrations of metal ions would not likely be produced because corrosion rates are slow in comparison to the mixing and dilution rates associated with marine environments. Insubstantial quantities of unspent propellants may also fall into the ocean. Unspent solid propellant dissolves slowly, and impacts to marine life are expected only in the immediate vicinity of the remaining propellant, if at all. Unspent liquid propellants such as liquid oxygen and liquid hydrogen pose no toxic threat to the marine environment; however, liquid fuels, such as kerosene, which are relatively insoluble in water, pose a slight risk to the marine environment until evaporation occurs. Hydrazine fuels are soluble and would disperse rapidly. The insubstantial quantity of propellant would form a thin film that would be broken up by wave action, sunlight, and oxygen. All traces of propellant would quickly dissipate within 1 to 2 days. Due to the insubstantial quantity of liquid fuel remaining in reentered hardware, no significant environmental impact is expected.

The presence of miscellaneous materials such as battery electrolytes and hydraulic fluids would be in such small quantities that only temporary effects would be expected (NASA, 1997a).

In the event of a launch failure, debris from reentered hardware could impact the ocean much closer to shore than would occur with a successful launch, and could result in more substantive impacts. However, the probability of such an event is extremely small (estimated at 1 percent probability); therefore, such an event should not pose a significant environmental impact (NASA, 1997a).

The probability for accidental release of rocket propellant in the early stage of flight is small (estimated at 1 percent probability). Rockets launched from WFF are equipped with radio receivers and ordnance for in-flight destruction if the flight is determined to be erratic. The system is designed to terminate rocket motor thrust upon activation; however, it is possible that a portion of the fuel may fall into the ocean. Due to the low toxicity of ammonium perchlorate leaching from the propellant, impacts to marine life would occur only in the immediate vicinity of the propellant, if at all. Toxic concentrations of ammonium perchlorate would be quickly dissipated by the ocean currents.

A 1986 Department of Transportation (USDOT) Programmatic EA discusses the accidental release of an entire load of kerosene from an Atlas rocket in the ocean. An Atlas is a liquidfueled main stage rocket that is substantially larger than any rocket expected to be launched from WFF. Evaporation of the thin film of liquid propellant released from an Atlas rocket is rapid. While evaluating the accidental release from an Atlas, the USDOT determined that "due to the relatively small area involved and fleeting nature of the phenomena, no significant environmental effect is expected" (USDOT, 1986).

Payloads

A payload entering the marine environment as a result of a launch accident could result in water quality impacts. The payload could contain metals, electrical components, propellant, radioactive materials, biological agents, or chemicals. Depending on the exact components of the payload, this type of accident could result in degraded water quality and impacts to aquatic life. The probability of an accident that could cause significant water quality impacts is small.

Groundwater

The accidental release of hazardous materials, including fuels, from operational activities or an accident could impact water resources at WFF by contaminating groundwater. Strict compliance with the ICP should minimize the risk of accidental releases of hazardous materials that could impact groundwater and minimize impacts to groundwater should an accidental release occur.

Wetlands

Rockets

Ground cloud formation from rocket launches may result in short-term impacts to vegetation in the areas surrounding the launch pads. Loss of vegetation may cause soil erosion and subsequent leaching of sediments, particulate matter, and nutrients that may eventually discharge into wetland areas. Increased sediment, particulate, and nutrient loads have the potential to negatively impact benthic species in the wetland system (NASA, 1999a).

Sediments and particulates can smother benthic organisms. Excess nutrients can cause algal blooms that deplete the water of dissolved oxygen and reduce the amount of light that reaches the bottom, resulting in degraded habitat for benthic species. Historic losses of vegetation around launch pads have not been substantial. The loss of vegetation surrounding launch pads from increased future launches is not anticipated to be substantive and no significant impacts are anticipated from ground cloud formation.

4.3. Air Quality

Rockets

Potential air quality impacts in the atmosphere from the burning of solid and liquid fuels have been examined in the troposphere and stratosphere (USDOT/FAA, 2001). No change is anticipated in the mesosphere or ionosphere.

Atmospheric pollutants can be divided into two general categories: 1) "criteria" pollutants, which include ozone (O3), carbon monoxide (CO), nitrogen dioxide, sulfur dioxide, particulate matter less than 10 and 2.5 microns in diameter, and lead; and 2) greenhouse gases (GHGs), which include carbon dioxide (CO2), methane, nitrous oxide (N2O), O3, and several hydro- and chlorofluorocarbons. Each GHG is assigned a global warming potential (GWP), which is the gas's ability to trap heat; GWP is standardized to CO2, which has a GWP value of 1. For example, N2O has a GWP of 310, meaning it has a global warming effect 310 times greater than CO2 on an equal-mass basis. For simplification, total GHG emissions are often expressed as a CO2 equivalent (CO2e). GHGs are relatively stable in the atmosphere and are essentially uniformly mixed throughout the troposphere and stratosphere; therefore, the source location does not affect the climatic impact of GHG emissions, and regional climate impacts are likely a function of global emissions. The layer of atmosphere closest to the Earth's surface is the troposphere. This layer extends from sea level to about 18 km. The mixing layer (sometimes referred to as the boundary layer) is the layer of air, within the troposphere, directly above the Earth that is relatively well mixed. This layer extends to a height of approximately 915 m, referred to as the mixing height, above which the free troposphere extends to the tropopause. Typically, temperature and density decrease with altitude in the atmosphere up to the mixing height. At the mixing height, however, the temperature begins to increase with altitude and creates an inversion that prevents air borne emissions from rising past the mixing height (Visconti, 2001). Almost all of the airborne pollutants emitted into the ambient atmosphere are transported and dispersed within the mixing layer. Since completion of the 2009 Final EA, in October 2010, MARS obtained a stationary source air emissions permit from the VDEQ for operating Pad 0-A as a liquid-fueled rocket engine test stand (i.e., to conduct static fire tests). Among other requirements, the permit includes a 26.2 tons per year emissions limit for CO. Under the Clean Air Act, permits are not required for emissions of criteria pollutants from mobile sources. Therefore, as a mobile source CO emissions from Antares launches are not considered when determining compliance with the annual permit limit.

The primary emissions from the launch of either configuration of the Antares ELV would be CO, CO2 and water vapor resulting from the combustion of the rocket's first stage propellants – RP-1 and LOX. Emissions of CO2 are calculated for the entire first stage flight profile because GHGs are not limited by the mixing layer of the atmosphere. For the assessment of GHGs, 25,000 tonnes is applied as a threshold below which such emissions would be considered minor.

On a per-launch basis, the 200 Configuration Antares ELV would emit approximately 9.4 tons of CO within the mixing layer, resulting in a total of approximately 56.6 tons per year for six launches. Orbital ATK is proposing to conduct static fire testing of the first stage but for a shorter duration than originally conducted for the 100 Configuration Antares. As such, each approximately 20-second static fire test would emit approximately 3.4 tons of CO, for a total of approximately 63.5 tons of CO emitted per year for two static fire tests and six launches. Greenhouse gas (i.e, CO2) emissions for the 200 Configuration Antares would contribute approximately 660 tonnes over six launches per year and, at approximately 5.8 tonnes per event, static test fires would contribute approximately 11.6 tonnes per year for two tests. Therefore, in total, approximately 671.5 tonnes of CO2 would be emitted per year.

4.4. Noise

Rockets

As long as the rocket motors on the launch vehicles are burning, noise would be generated, especially at the lower altitudes when the air density is appreciable. The attenuation due to increasing distance and the thinning of the atmosphere would reduce sound transmission. Above a 10-kilometer (6.21-mile) altitude where vacuum conditions are approached, no sound would be propagated. When the rockets become spent, only aerodynamic noise would prevail as the spent rockets (and there may be two, three, or four stages in a launch vehicle) follow a ballistic path to the water. Oblique shock systems are formed as the denser air slows down the incoming projectile objects to lower but still supersonic speeds near the 1,000 meters per second (0.62 mile/second) level.

The launch areas on the island are located approximately 4.02 kilometers (2.5 miles) from the mainland. The marshland and water surrounding the island act as a buffer zone for noise generated during rocket launches due to the sound absorption capacity of the vegetation.

Rockets are generally launched over water from Wallops Island and the noise generated is usually low frequency and of short duration. Rocket launches can be heard throughout the surrounding community; however, not at levels that generate complaints or damage property. All non-essential personnel are evacuated from the safety zone during a launch. All essential personnel are restricted to a blast-proof building called a blockhouse. Personnel outside the hazard area may be restricted to their buildings depending on the size of the hazard area.

The impact of spent rockets or unrecoverable payloads as supersonic projectiles would produce momentary sounds as the water surface is broken. When payload recovery is desired, usually a parachute is deployed at an altitude of about 6 kilometers (3.7 miles) to slow down the payload for aerial or water recovery. For aerial recovery, specially equipped aircraft or helicopters are used to locate and retrieve the payload prior to splashdown. The payload is then transported directly by the recovery plane/helicopter to a landing area support facility. For water recovery, USCG cutters are used. The noise generated by these vehicles while searching for, recovering, and transporting the payload to the support facility is comparable to that from normal daily transportation activities. The splash site, however, may be in a remote area that is seldom visited by automobiles or aircraft. Nonetheless, the noise generated during recovery operations should not exceed 110 dB and is of short duration. Therefore, no substantial adverse noise impacts are expected.

Birds are most sensitive to noises at far higher frequencies than those associated with launch vehicles. Birds may be startled by impulsive noises created by rocket launches, but because launches are infrequent as described in the proposed action, this impact is not significant.

Despite the noise from rocket launches, the piping plover population has survived and continues to nest in the Wallops Island area. Mammals seem to be less disturbed by noise than birds, but startle effects can still occur.

In addition to the noise of the rocket engine, sonic booms are possible. A sonic boom is a sound that resembles an explosion and is produced by a shock wave that forms at the nose of a vehicle that is traveling faster than the speed of sound. The potential for, and the intensity of, a sonic boom being heard on the surface of the Earth depend upon the vehicle length, the nose cone shape, the trajectory of the launch, the vehicle velocity, and weather conditions.

As the launch vehicle rises from the pad and achieves supersonic speed, the shock wave is projected over the horizon without impacting the Earth's surface. After launching almost vertically, the vehicle begins to tilt, or pitch over, a maneuver designed to align the vehicle's path more closely to that of an orbit around the Earth. Pitch-over also points the shock wave downward towards the Earth's surface where the sonic boom can be heard.

Sonic booms are only permitted to occur over the ocean so no negative noise impacts to humans should occur. Ocean-going vessels would be expected to experience sound resembling mild thunder (USDOT/FAA, 1996). Sonic booms from launches could also impact underwater environments. These types of booms represent a threat of physical and physiological impairments to marine animals in the vicinity of the water surface, particularly if these animals are in the relatively restricted impact zone of the boom.

4.5. Hazardous Materials and Hazardous Wastes

The greatest potential impact to the environment due to the release of hazardous materials would result from an accident at a storage location (e.g., leak, fire, or explosion) or, to a lesser degree, from an accidental release during normal operating activities (e.g., spills or human exposure). The short- and long-term effects of an accident on the environment would vary greatly depending upon the type of accident and the substance(s) involved. NASA has implemented various controls to prevent or minimize the effects of an accident involving hazardous materials, including the following:

- NASA has prepared an ICP;
- NASA has prepared emergency plans and procedures designed to minimize the effect an accident has on the environment;
- GSFC maintains an online database (MSPro®) of hazardous materials and the associated buildings where they are stored or used; and
- Training is provided annually for all users of hazardous materials.

Rockets

All hazardous materials associated with rocket operations are managed with standard procedures. Guiding principles include proper containment, separation of incompatible and reactive chemicals, worker warning and protection systems, and handling procedures to ensure safe operations. All personnel working in the M-area (rocket motor assembly, integration, and storage) receive HAZCOM training. Hazardous wastes are also managed according to standard procedures. Operational requirements and personnel training requirements are followed by all personnel involved with motor assembly, integration, and storage. It is not anticipated that an increase in rocket operations would significantly impact human health or the environment.

5. Biological Environment

5.1. Vegetation

Rockets

Primary impacts to vegetation in the vicinity of WFF rocket launch pads would result from exhaust products such as gases, high temperature, and fire. The most sensitive environmental areas on Wallops Island are located near the launch pads comprising

Launch Complex 0. Launch Complex 0 is located on the south end of Wallops Island near the OB area. Since the largest rockets being launched from WFF leave from Complex 0, the following analysis pertains to that area. Impact to vegetation at smaller launch complexes would be similar, but less extensive. Damage to vegetation resulting from launch activities can be anticipated within a 1,000-meter (3,280-foot) radius of the launch pad. The principal impacts would radiate out approximately 200 to 300 meters (656 to 984 feet) from the combustion path. Searing of vegetation can occur within this radius (NASA, 1997a). Launch Complex 0 contains flame trenches that direct the principal exhaust and flames toward the beach and over the open ocean. The flame trench directs the principal impacts away from the undisturbed marshes and piping plover habitat located west and south of Launch Complex 0, respectively.

Exhaust emissions of hydrogen chloride produce short-term acidic conditions, and can result in vegetation mortality adjacent to the launch pad. Studies of Space Shuttle launches on vegetation revealed that thick cuticled plant species and grasses that are adapted to harsh salt environments are more tolerant to launch conditions (NASA, 1997a). This study suggests that vegetation communities adjacent to the launch pad can evolve into grass and herb communities that are more tolerant. At WFF, wax myrtle (Myrica cerifera) is common in the vicinity of Launch Complex 0 and is fairly resistant to near-field effects. This tolerance should prevent a major transformation of the vegetation community (NASA, 1997a). The impacts to vegetation from rockets are considered temporary due to the infrequencies of launches and the observed recovery of the vegetation between launches.

5.2. Terrestrial Wildlife and Migratory Birds

Rockets

The primary impacts to wildlife and migratory birds in the vicinity of WFF rocket launch pads result from exhaust products such as gases and fire, as well as noise. The most sensitive launch areas on Wallops Island, from an environmental perspective, are the launch pads comprising Launch Complex 0. Since the largest rockets launched from WFF leave from Complex 0, the following analysis pertains to that area. Impacts to wildlife and migratory birds at smaller launch complexes would be similar, but less extensive. Impacts to wildlife and migratory birds, resulting from launch activities, can be anticipated within a 1,000-meter (3,280-foot) radius of the launch pad. Temporary impacts to wildlife activities would be expected within this area for 2 to 10 minutes during launch operations. The principal impacts would radiate out approximately 200 to 300 meters (656 to 984 feet) from the combustion path. Injury or death to wildlife and migratory birds could occur within this zone (NASA, 1997a). The fire trench would limit injury and death of wildlife and migratory birds to the beach and open ocean rather than south and west where more suitable habitat exists. It is anticipated that there would be no significant impact to wildlife or migratory birds due to the infrequency of launches at Complex 0. Noise generated from rocket launches is generally of low frequency and short duration.

Temporary interruption of foraging and nesting activities in the immediate area of the launch pad may occur. Due to the short duration of the noise disturbances, no significant impacts are anticipated (NASA, 1997a).

Wildlife exposed to elevated sound pressure levels from ELV launches are expected to exhibit a startle response that could interfere with normal behaviors, including breeding, feeding, and sheltering. This may include flushing birds from nests when incubating eggs, interruption of feeding or courtship, or similar responses. The combination of the sound with a visual stimulus such as a rocket in flight is expected to magnify the startle responses, particularly for those species in close proximity to the launch sites. Because the noises associated with rocket launches are infrequent and of short duration, wildlife species are expected to return to normal behavior within a few minutes to hours following the disturbance. Due to the reproductive cycle of potentially affected species, potential disruption of breeding activities would happen between the months of April and August. Launches from Pad 0-A would occur well south of the areas of the beach that have historically hosted the greatest level of avian nesting activity. However, the presence of the renourished beach could attract birds into areas where launches would occur; thereby, increasing the probability for adverse interactions. Effects on prey availability are expected to be a contributing factor, and given that the renourished beach is likely to remain in a biologically suppressed state for the foreseeable future, it is probable that avian species would continue to congregate on the more forage-rich areas of north Wallops Island. The potential effects of launch-induced fires on wildlife would be species-specific, and largely dependent upon one's ability to detect and avoid the fire.

In the event of a launch failure, it is possible that wildlife could be exposed to perchlorate containing water, which, if the uptake is in large enough quantities, could induce various physiological effects, including changes to hormone production, development, and reproduction (Dean et al., 2004). However, it is not expected that wildlife species would ingest appreciable quantities of perchlorate, as the waters surrounding Pad 0-A are saline (e.g., Chance, 2014), rendering their value as a drinking water source for most species very low. To summarize, the general consensus in the scientific literature is that perchlorate demonstrates a general lack of bioconcentration in wildlife and avian species (Dean et al., 2004; ITRC, 2005). Therefore, when considered with the low concentrations of perchlorate expected to occur in surface waters, and generally limited exposure pathways, the effects of a launch failure on wildlife or migratory birds would be minor.

5.3. Threatened and Endangered Species

Rockets

Rocket launches have the greatest potential to impact the piping plover. Through consultation with USFWS, NASA has developed a monitoring plan to better understand the effects of rocket launches on piping plover behavior. The monitoring of piping plovers on the south end of Wallops Island would occur during the first three launches from launch pad O-B that take place between March 1 and September 15. Monitoring would be conducted daily for 7 consecutive days prior to a launch, during the launch (as dictated by human safety considerations), and for 7 consecutive days after the day of the launch. If it is not possible to monitor during the launch, monitoring would occur immediately before and after the launch.

Monitoring would occur for an hour early in the morning and late in the evening when avian species are more active. Depending on the results of the surveys, and at the discretion of the USFWS, additional years of monitoring may be required and new determinations on impacts may be made by NASA and the USFWS.

Until launch pad O-B is used and monitoring data are made available, NASA and USFWS do not anticipate that the proposed action would incidentally take any piping plovers due to the short duration of the disturbance, the long distance between the disturbance and the area used by plovers, the limited number of launches during the nesting season, and the lack of other disturbances (e.g. recreation) to the plovers at this site.

PART III: POTENTIAL IMPACT ON OUTER SPACE

1. Antares rocket

The 2 stages and the fairing of Antares are de-orbited. There is therefore no impact on outer space caused by the Antares rocket.

2. Cygnus spacecraft

After staying typically 30 days docked to the ISS, the Cygnus spacecraft is released. It performs several engine burns to de-orbit and re-enter the atmosphere over the Pacific Ocean. During re-entry, the vehicle breaks up and burns up to some extent before surviving fragments fall into the Pacific, far away from populated land masses. There is therefore no impact on outer space caused by the Cygnus spacecraft.

3. ISS operations

The NanoRacks CubeSat Deployer (NRCSD) is a self-contained CubeSat deployer system that mechanically and electrically isolates CubeSats from the ISS, cargo resupply vehicles, and ISS crew. The NRCSD design is compliant with NASA ISS flight safety requirements and is space qualified.

4. CubeSats

4.1. Typical CubeSats

The orbit of the CubeSats will naturally decay and CubeSats will be fully destructed while re-entering the atmosphere. This will happen less than 5 years after deployment for the considered orbit.

4.2. Re-entry experiments

Two of the CubeSats boarded will have reentry experiments, specifically:

Name	Country	Size	Experiment
QARMAN	Belgium	3U	QARMAN is a reentry cubesat, expected to survive reentry
GamaSat	Brazil	3U	Gamasat will release a small reentry capsule (called GamaDrop) expected to reentry

Both the CubeSats to be deployed from the ISS have to pass a 3-phases safety review, which includes the check of casualty risk associated to reentry.

4.2.1. QARMAN

QARMAN has passed phase 1 and 2 of the NASA safety review, clarifying all the issues and closing all the actions related to the casualty risk analysis.

Simulations have been performed assuming both break-up and ground impact without break-up (the baseline scenario) of QARMAN to quantify the risk of human casualties. In the latter case, a material with high melting temperature was applied to QARMAN modeled as a solid body. For the other option with break-up due to structural failures, major components like front, side and back TPS, together with the panels, batteries and reaction wheel has been chosen for the simulation due to their high mass or melting temperature.

The simulations are performed with ESA DRAMA software (version 2.0.2)

The QARMAN team considered two types of break-up:

- AeroSDS panel detachments with the QARMAN main body intact
- QARMAN total disintegration due to excessive aerodynamic forces (tumbling combined with heating).

All cases in the analysis for the baseline with no break-up and partial break-up result in a casualty probability which is lower than the threshold of 1 in 10000, as specified in IPOL(2014)2[5]. However in case of the unlikely complete break-up, a maximum risk of 1 in 7553 for causalities is observed. It is VKI's opinion that the break-up of QARMAN is unlikely (assumed to be less than 25% of probability) and in case of break-up, the panels will only detach with the QARMAN main body intact. However due to the complex system, interconnection between the aerothermodynamics and flight mechanics (uncertain flight conditions), a precise estimation of likelihood or probability can be not given.

In case of non-deployment of the AeroSDS due to either software or hardware failure, the estimated lifetime in orbit will be approximately 0.38 years (138 days) assuming a mass of 5 kg and ram-direction flight resulting in a drag coefficient of 3.3 and a deployment at 400km of altitude.

A detailed study (*QARMAN Deliverable D1AB.2 - Space Debris Mitigation Plan (SDMP)*) is provided in Annex 2.

4.2.2. GamaSat / GamaDrop

GAMADROP is an atmosphere re-entry experiment on-board GAMASAT-1. GAMADROP is a reentry capsule, with a cross sectional diameter of 95mm, to be released from inside GAMASAT-1 for reentry purposes.

GamaDrop experiment has been designed to be compliant with NASA regulations in term of casualty risk and safety: Requirement 4.7-1 of the NASA Technical Standard 8719.14 - Process for Limiting Orbital Debris outlined below [R1]: 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) (Requirement 56626).

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[5] ESA/ADMIN/IPOL(2014)2, space debris mitigation policy for Agency Projects, article 2-b *"[...] the casualty risk shall not exceed 1 in 10,000 for any re-entry event (controlled or uncontrolled). If the predicted casualty risk for an uncontrolled re-entry exceeds this value, an uncontrolled re-entryis not allowed and a targeted controlled re-entry shall be performed in order not to exceed a risk level of 1 in 10,000".*

Similarly to QARMAN, GamaSat (with the GamaDrop experiment) has passed NASA approval for reentry, demonstrating the compatibility via simulations, identifying a casualty risk of 1:197600, way lower than the requirement (1:10000).

A detailed study (*GamaSat Re-Entry Casualty Risk Analysis Report*) is provided in Annex 3.

PART IV: NON-TECHNICAL SUMMARY

In the framework of the EU FP7 Project aiming at the launch of 50 CubeSats for atmospheric research, the VKI as coordinator of the project, have procured by the launch service through the US Company NANORACKS LLC, for a cargo flight to the ISS, to be performed with an Antares rocket operated by Orbital ATK (OA-7 mission of NASA). NANORACKS has extensive experience in this typology of launch service for CubeSats, foreseeing an upload to the ISS and a successive deployment from the robotic arm of the station, including everything related to safety and risk mitigation: at the date, NANORACKS has either uploaded more than 110 CubeSats to the ISS, having all of them cleared for flight from NASA, from a safety perspective.
As shown in this document, NANORACKS is supporting the launch and deployment management, for the cargo mission to upload the CubeSats on the ISS. Nevertheless, to be cleared for flight, all the hardware has to pass through a safety review from NASA.

As an Operator located in Belgium and therefore subject to the Belgian law of 17 September 2005 (revised by the law of 1 December 2013) on the activities of launching, flight operation or guidance of space objects, the VKI is responsible to providing to the Belgian authorities an environmental impact assessment of the foreseen launch activity.

As shown in section II, the safety and environmental impact of the launches with an Antares Rocket from the Wallops Flight Facility (WFF) is closely monitored and periodically updated, guaranteeing a sustainable space launch activity.

Several mitigation activities and ongoing environmental practices contribute to reduce or limit the potential environmental impact of the launch: please refer to section II for details.

Based on financial, technical and programmatic assumptions, the selected launch vehicle, through the launch service offered by NANORACKS, offers the best guarantees for the realization of the launch objectives. Nevertheless, launching space objects into outer space is never without risks and especially potential negative impact on the environment can never be completely excluded. We think however the environmental impact has been assessed and has been analyzed. For the QB50 project, being a scientific endeavor with limited budget, the selected launch solution offers the best value for money.

PART V: MEMO ON THE EXPERTISE OF THE VON KARMAN INSTITUTE FOR FLUID DYNAMICS AS OPERATOR

1. Introduction: Implementation of the Belgian space law

The QB50 project, funded by the European Commission and executed by the von Karman Institute for Fluid Dynamics (VKI) intends to launch 47 nanosatellites into Low Earth Orbit by means of 2 distinct launches. The object of the present document is the launch of 39 nanosatellites by an Antares rocket followed by a deployment from the International Space Station to an altitude of approximately 410 km at an inclination of approximately 52 degrees. The VKI will act as the Operator in the framework of the Belgian space law, but implements the launch activity through an American launch service provider (Nanoracks LLC).

The relationship between the aforementioned partners is illustrated in Figure 8.

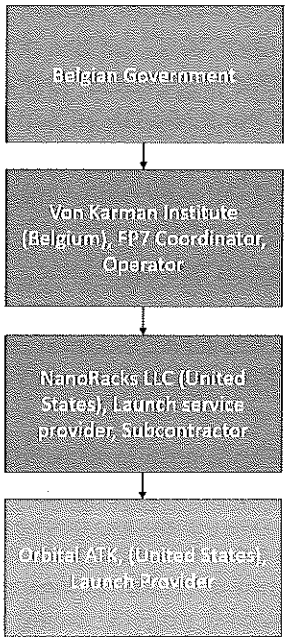

Figure 8 – Implementation of the Belgian space law with respect to the QB50 ISS launch campaign.

2. Expertise as an Operator

VKI is a non-profit international educational and scientific organization, hosting three departments[6]. It provides post-graduate education in fluid dynamics and encourages "training in research through research". The VKI undertakes and promotes research in the field of fluid dynamics. It possesses about fifty different wind tunnels, turbomachinery and other specialized test facilities, some of which are unique or the largest in the world. Extensive research on experimental, computational and theoretical aspects of gas and liquid flows is carried under the direction of the faculty and research engineers, sponsored mainly by governmental and international agencies as well as industries.

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[6] Aeronautics and Aerospace (AR), Environmental and Applied Fluid Dynamics (EA), Turbomachinery and Propulsion (TU)

The VKI is or was involved in the instrumentation of all ESA re-entry spacecraft such as the Atmospheric Reentry Demonstrator (ARD), European eXPErimental Reentry Testbed (EXPERT), the Intermediate eXperimental Vehicle (IXV) and has started in 2010 to design, end-to-end, its own miniaturized re-entry vehicle called Qarman.

As of 2011, the VKI is charged with the management of the QB50 project consisting of the launch of 50 CubeSats. In the framework of the QB50 project, three precursor satellites were launched on the 19th June 2014 under the authorization number 2014/01 (objects 2014-B-SC-001, 2014-B-SC-002, and 2014-B-SC-003). They have been operated by the VKI since then.

The QB50 team of VKI involved in (the preparation of) the launch consists of the following persons:

Name	Responsibility
Dr. Jean Muylaert	Director VKI, FP7 QB50 General Supervisor
Dr. Davide Masutti	QB50 Project Manager
Thorsten Scholz	Ground Segment Engineer and Mission Analyst
Paride Testani	Launch and Space Segment Engineer
Amandine Denis	Space Segment Engineer & CubeSat Coordinator

Detailed curriculum vitae of the persons involved from VKI is attached in Annex 1.

3. Alternative launcher scenario's analysis

In accordance with the provisions of the Belgian space law, VKI conducted an in depth analysis of the European and international launchers potentially available for realizing the objectives of the QB50 ISS launch. The results of this analysis are described in this chapter.

The launch scenario consisting of the choice of provider, the launch site and further characteristics such as contractual conditions have been analysed to best match the needs of the QB50 project, the Regulations of the EU FP7 program and other constraints. The disregarded alternatives and the reasons are given below:

Launch Provider and Launcher	Reason for disregard
ESA/Arianespace • VEGA • ARIANE 5 • SOYUZ	In particular the launch cost is prohibitively high. Further reason for disregard is the timely unavailability of a launch into a suitable Low Earth Orbit
American Launch providers such as United Launch Alliance, Orbital Science, SpaceX • Atlas 5 • Antares • Falcon 9	The costs for the launch are prohibitively high. Further reason for disregard is the timely unavailability of a launch into a suitable low Earth Orbit
Chinese launch providers such as China Great Wall Industry Corporation (CGWIC) • MLVT • Long March	Mostly export related issues prevented the consideration of Chinese provided launch vehicles.
Russian launchers such as DNEPR	The DNEPR program suffers from severe delays and is apparently on-hold.

ANNEX 2 – QARMAN SPACE DEBRIS MITIGATION PLAN (SDMP)

von Karman Institute for Fluid Dynamics
Aeronautics / Aerospace Department

Chaussée de Waterloo, 72
B - 1640 Rhode Saint Genèse
Belgium

QARMAN Deliverable D1AB.2
Space Debris Mitigation Plan (SDMP)

WP AB11, D1AB.2

Contract Report: VKI CR 2015-23
Internal Ref.: 14/VKI/VDH/ARR1310/D1AB

QubeSat for Aerothermodynamic Research and
Measurements on AblatioN

Von Karman Institute
for Fluid Dynamics

DOCUMENT REVISIONS TRACEABILITY SHEET

DOCUMENT 14/VKI/VDH/ARR1213/D1AB
VKI CR 2015-23

Rev. 1	***Date:*** 5 Jan 2014	***Status:*** issue	No. of pages: 10
Title: Space Debris Mitigation Plan (SDMP) Author(s): T. Scholz, P. Testani Reviewed & Approved by: V. v.d.Haegen Features: First issue for SDMP			
Rev. 2	***Date:*** 8 May 2015	***Status:*** issue	No. of pages: 12
Title: Space Debris Mitigation Plan (SDMP) Author(s): T. Scholz Reviewed & Approved by: V. v.d.Haegen Features: Updated SDMP according to changed design (survival units) and increased mass			
Rev. 3	***Date:*** 22 June 2015	***Status:*** issue	No. of pages: 16
Title: Space Debris Mitigation Plan (SDMP) Author(s): T. Scholz Reviewed & Approved by: V. v.d.Haegen Features: Compliance verification matrix added as per CDR RID #70; list of applicable documents and reference documents.			
Rev. 4	***Date:*** 15 Feb. 2016	***Status:*** issue	No. of pages: 17
Title: Space Debris Mitigation Plan (SDMP) Author(s): T. Scholz Reviewed & Approved by: V. v.d.Haegen Features: Updated orbit to ISS.			
Rev. 5	***Date:*** 20 Jul. 2016	***Status:*** issue	No. of pages: 22
Title: Space Debris Mitigation Plan (SDMP) Author(s): T. Scholz Reviewed & Approved by: V. v.d.Haegen Features: Updated failure modes for break-up (partial and complete break-up)			

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Acronyms

ADCS	Attitude Determination and Control Subsystem
A(ero)SDS	Aerodynamic stability and deorbiting system
COM	Communication
COTS	Commercial off-the-shelf
DAT	Data
DiffDrag	Differential drag payload
DR	Debris requirement
EoM	End of mission
EPS	Electrical power system
GEN	General
GPS	Global positioning system
LEO	Low earth orbit
LPM	Low power mode
LTAN	Local time ascending node
MSC	Mission Control Center
MEA	Measurement
MR	Mitigation requirement
OBC	On-board computer
OBJ	Objective
OPS	Operational
PHK	Payload and housekeeping (requirement)
QARMAN	Qubesat for Aerothermodynamic Research and measurements on ablation
REQ	requirement
SDM	Space debris mitigation
STL	Structural and thermal loads
STR	Structural (requirement)
S/W	Software
TBC	To be confirmed
TBD	To be determined
TCS	Thermal control and structural (requirements)
TPS	Thermal protection system
UHF	Ultra high frequency
ULg	Université de Liège
VHF	Very high frequency
VKI	Von Karman Institute
XPL	eXperimental PayLoad

1. Applicable and Reference Documents

1.1 Applicable Documents

1) ESA/ADMIN/IPOL(2014)2

2. Introduction

QARMAN is the "QubeSat for Aerothermodynamic Research and Measurements on AblatioN" of VKI, developed in the framework of QB50 project [i]. Different than other QB50 CubeSats, QARMAN will be designed to collect scientific data during its entry to Earth's atmosphere. Atmospheric entry and associated aerothermodynamic phenomena are considered as critical research topics for the safety of the spacecraft. The QARMAN Project aims at creating an affordable research platform to perform scientific studies in these fields.

2.1 Mission profile

The flight scenario of QARMAN is shown in the following figure.

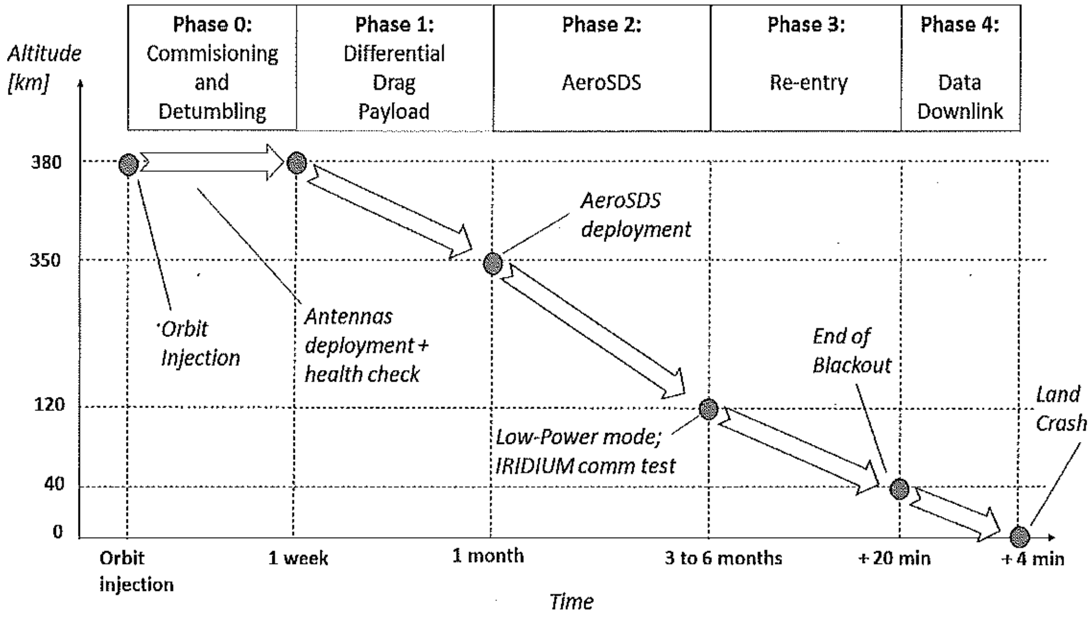

Figure 1 QARMAN flight scenario

The following table summarizes the subsequent mission phases:

Safe mode	This mode is intended to keep the satellite alive. All subsystem are OFF except: OBC, VHF com (uplink), Beacon, UHF com (downlink) for housekeeping.
Commissioning& Detumbling	This mode is used to de-tumble the spacecraft after ejection from the deployment dispenser and to establish connection with the ground. The mode starts after the ejection. After a waiting time of 30 min (requirement by QB50 to guarantee separation of

	CubeSats) the antennas are deployed and detumbling begins after an initial autonomous health check. This mode is expected to be the most demanding for the ADCS, and thus only OBC, beacon, and UHF transceiver are ON. Any other device could be turned ON by ground command. After detumbling is completed (below 1°/min), functional tests of the different payloads are performed. This phase is expected to last 2 days after the deployment of the satellite.
Differential drag	This mode is aimed at performing differential-drag-based manoeuvres. The subsystems exploited in this phase and directly involved in the payload are: ADCS (all the sensors and actuators), GPS, UHF transceiver. The other active systems are OBC and beacon.
AeroSDS	This mode is intended to verify the feasibility of the AeroSDS by measuring the degree of stability (accelerometer, gyroscopes, pressure sensor), the drag increase (accelerometer, GPS) and impact on the structure (moment and forces on panels). The ADCS(actuators) is turned OFF, the UHF communication system and beacon ON. In preparation of Phase 3 a system tests of IRIDIUM will be performed prior to LPM.
LPM, low power mode	This mode assures full batteries for the Phase 3 (Re-entry). During LPM, only necessary systems will be turned ON (OBC, EPS, COMM systems in receiving mode). The duty cycle for measurements (GPS, accelerometers, gyroscopes) will be reduced to a minimum. ADCS (actuators) are turned OFF.
Re-entry (data collection and downlink)	This mode is used during Re-entry with measurements performed to access the TPS recession/ablation and the radiation by the plasma sheet around QARMAN. UHF communication, Beacon, ADCS(actuators) and GPS is turned OFF; IRIDIUM and the payload sensors (incl. IMU) for this phase are turned ON. System reboots is prohibited in this phase (watch-dog disabled)!With respect to what was described in the PRD of QARMAN, this phase has been split in two parts: data collection and data transmission (phases 3 and 4 respectively). This is simply a practical distinction, introduced as consequence of the differences in functions and operations performed during re-entry and does not change the typology and the nature of the operations performed.

2.2 Orbital parameters

The launch of QARMAN will be performed in the framework of QB50 which enforces the orbit properties on all the participating CubeSats. The launch and deployment of QARMAN will be performed utilizing the ISS and Nanoracks launch service. Hence, the orbit will be similar to the ISS orbit.

The values for the orbit parameters are:

Altitude	h = 400 km
Inclination	i = 51.6°
LTAN	any

According to the last issue of the QB50 system requirements (issue 7), the compliancy with any initial LTAN has been required.

3. Space debris mitigation

3.1 Modes of failure

For the risk assessment of the re-entry for QARMAN, two failure modes have been assumed depending on the severity of the break-up.

The first case assumes, that QARMAN will undergo a sever break-up process including the detachment of the AeroSDS panels and consecutive separation of the side-TPS ceramics (intact parts) and internal structure due to aerodynamic forces. Due to multiple restraints and connections between the internal structures itself and towards the side-walls, this case is considered unlikely.

The baseline case for break-up (partial) assumes that the AeroSDS panels will detach from QARMAN due to mechanical failure of the AeroSDS shafts (shearing) or the panels shaft holes (local fracture around hole, see Figure 2) due to excessive aerodynamic forces and moments. The likelihood that the AeroSDS hinge mechanism breaks is small with respect to the failure of the shaft hole inside the ceramic. The loss of one panel will lead to a strong pitching or yawing moment and as a consequence, the failure of the other panel mounting systems.

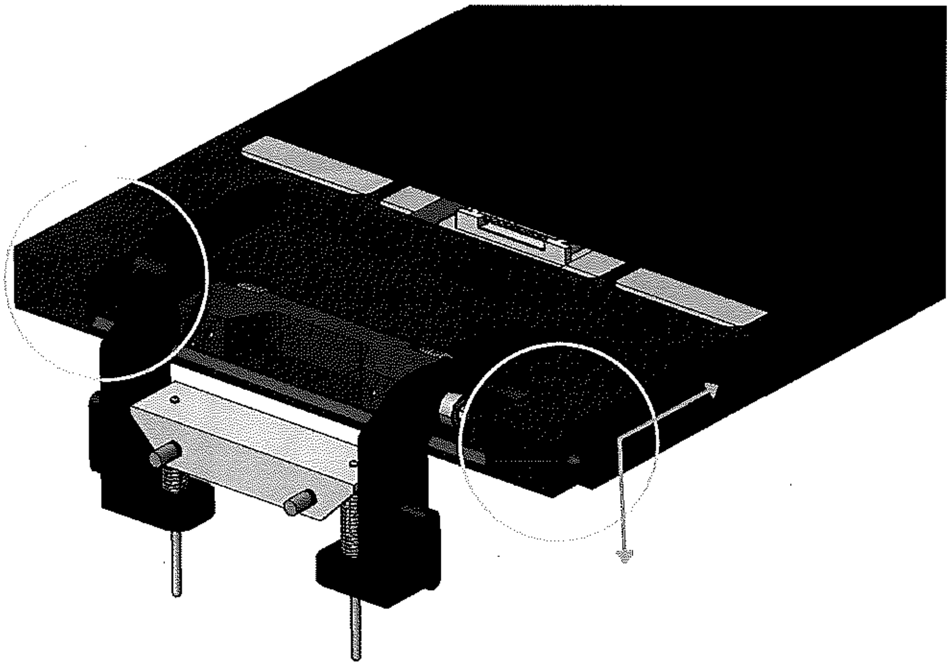

Figure 2 AeroSDS panel separation (shaft location); aerodynamic loads induce a down- and backward directed force on the panel during flight

The main-body of QARMAN is estimated to stay intact due to the complete surrounding of the vehicle with the TPS material P50 on the nose and ceramic side-walls and back-plate TPS protecting the internal frame/structure and sub-systems. The aerodynamic loads on QARMAN in case of tumbling should result in mostly inwards directed forces on the side-walls which is directed towards the titanium rails as part of the internal structure; the limited venting areas where an inflow of air can occur and induce an overpressure condition is shown in Figure 3. Due to the sealing of the front-compartment of the CubeSat via the AeroSDS survival-unit, the overpressure can likely only affect the back-plate with the tunacan extension (volume filled with insulating material) with is fixed with 8x M2.5 screws towards the back-frame. Due to the limited free volume around the hinge-arms and the filled cylindrical extensions, the forces on the back-plate expected to be less than the maximum tolerable force on the screws (~2.5kN each). Assuming a flight velocity of 7km/s and density of 1E-3 kg/m^3 representing worst-case conditions, the stagnation pressure induces a load of approximately 250N on the back-plate resulting in a safety factor of 10 for the selected screw.

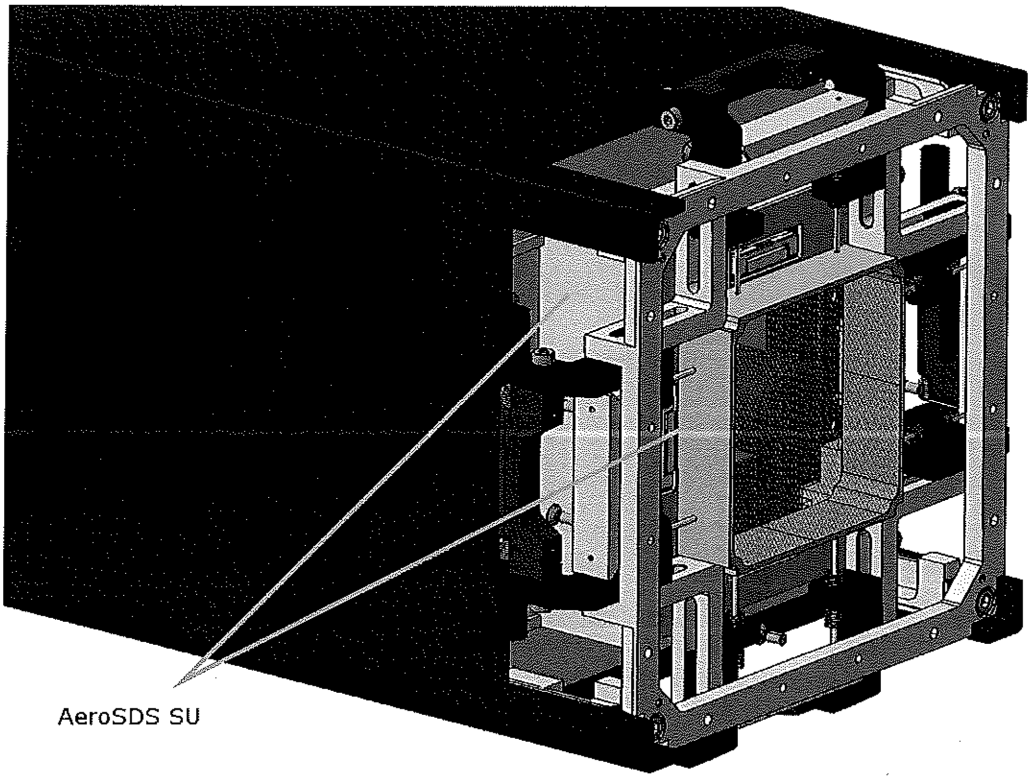

Figure 3 AeroSDS survival unit sealing the front part of the satellite

The side-wall elements are all slided over the internal rail-structure from the back of the satellite before integration of the AeroSDS Survival Unit and the back-frame. The detachment of the side-walls (in X and Y direction) is prevented by multiple hold-down systems which restrain the motion of the ceramics in lateral and longitudinal direction of the satellite. A failure of the hold-down elements or break-up of the ceramic parts (e.g. due to impact of the AeroSDS panels) would be required so shattered parts could detach from QARMAN. It should be noted so, that a thermal blanket is glued to the complete inside of the ceramic elements which will provide some support in case of cracking or shattering. No failure of the load-carrying metallic structure (Titanium) and the links (screws) are expected.

The side-wall constraints are shown in the following pictures from CAD and EM models.

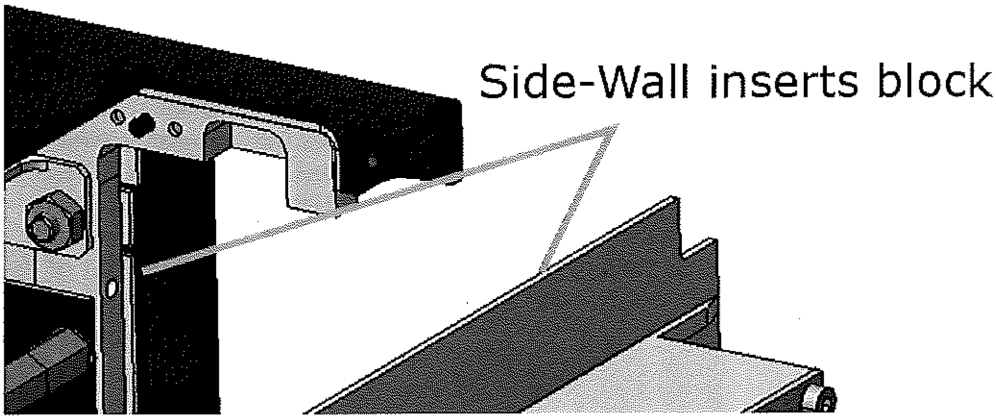

Figure 4 Mechanical contact (2 x 82 mm) with the AeroSDS SU preventing the back-wards sliding of the inserts;

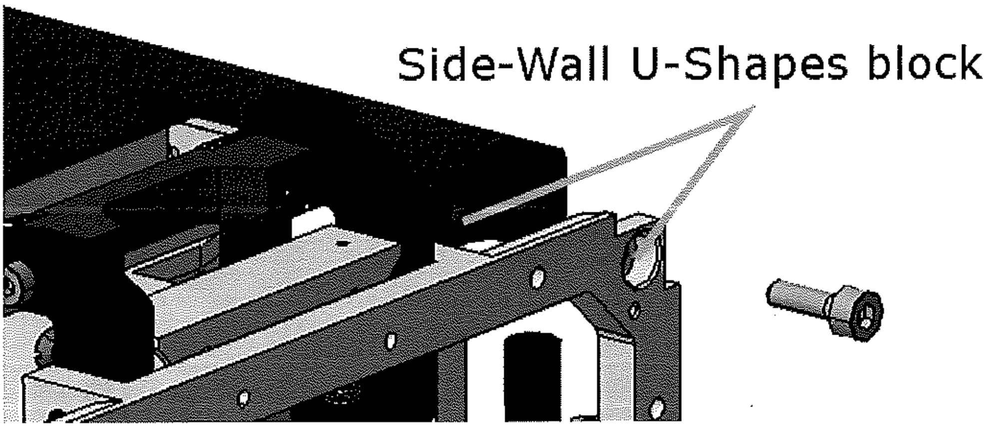

Figure 5 Mechanical contact between U-Shaped side-walls and back-frame. The 4x M2.5 screws attach the back-frame to the Rails;

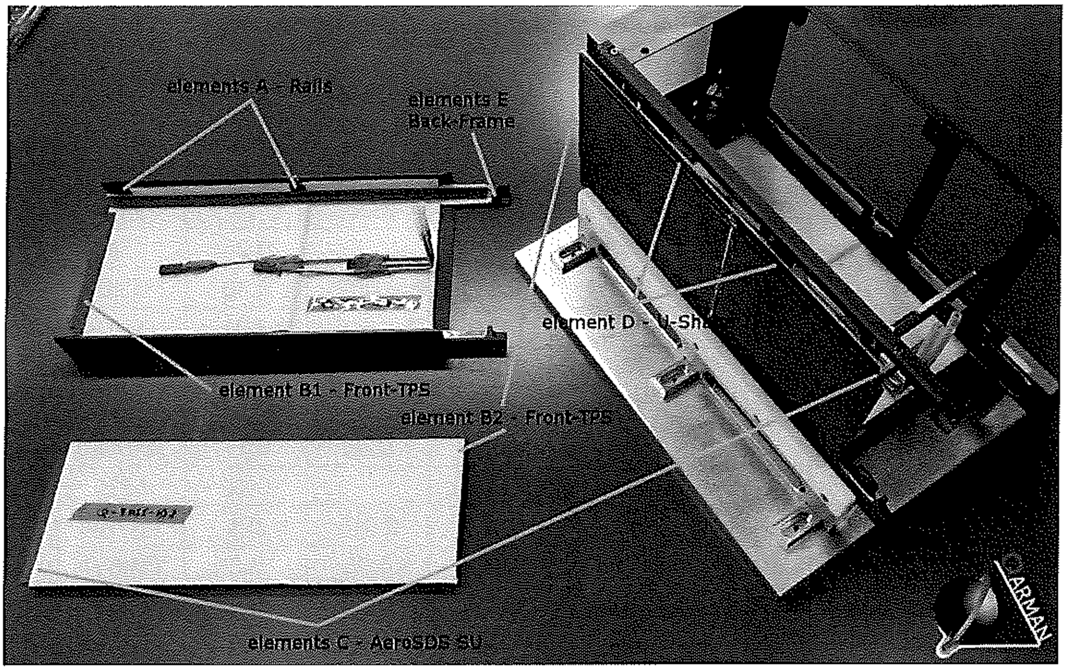

Figure 6 Side-Wall TPS (U-Shape / Inserts) with glued thermal protection blanket; elements A and B1 prevents the outwards motion of the U-shapes (±X direction); B2 and D the outwards motion of the inserts (±X direction); C and E prevent against Z direction motion

3.2 Input parameters

Simulations have been performed assuming both break-up and ground impact without break-up (the baseline scenario) of QARMAN to quantify the risk of human casualties. In the latter case, a material with high melting temperature was applied to QARMAN modeled as a solid body. For the other option with break-up due to structural failures, major components like front, side and back TPS, together with the panels, batteries and reaction wheel has been chosen for the simulation due to their high mass or melting temperature.

The simulations are performed with DRAMA (version 2.0.2) and the following parameters:

- Population density: 7.50E+09 total, 7.169E+09 in latitude range
- Orbit parameters:
  - SMA = 6505 km,
  - i = 51.6°
  - e = 0.01

An initial mass for QARMAN at the beginning of re-entry was set to 5kg. In case of break-up, the most important objects likely to survive are listed in Table 1 with references to the material properties stated in Table 2. The QARMAN team considered two types of break-up:

- AeroSDS panel detachments with the QARMAN main body (4kg) intact (likely case)
- QARMAN total disintegration due to excessive aerodynamic forces (tumbling combined with heating).

Table 1 Object definition for partial/complete break-up

Name	Shape	#Obj.	Width / Diameter [m]	Length [m]	Height [m]	Mass [kg]	Material
Parent	Box	1	0.1	0.34	0.1	5	n/a
SIDE_TPS	Plate	8	0.1	0.1		0.20	SSiC
PANELS	Box	4	0.082	0.031	0.007	0.30	SSiC
BACK_TPS	Plate	1	0.1	0.1	0	0.01	SSiC
NOSE_TPS	Sphere	1	0.7			0.36	Cork
PCBs	Plate	4	0.09	0.09		0.01	FR4
BATTERY	Box	1	0.09	0.09	0.01	0.17	AA6060
RWHEEL	Cylinder	1	0.06	0.04		0.16	A316
RAILS	Box	2	0.015	0.22	0.015	0.1	TiAl6V4
SU_OBC	Box	1	0.08	0.15	0.05	0.3	TiAl6V4
SU_XPL	Box	1	0.08	0.02	0.08	0.2	TiAl6V4
SU_ADCS	Box	1	0.1	0.01	0.1	0.2	TiAl6V4
NOSE_TPS_SS	Cylinder	1	0.06	0.05		0.2	SSiC
HINGE_ARM	Box	1	0.05	0.1	0.04	0.05	A316
BACK_FRAME	Box	1	0.1	0.03	0.01	0.1	TiAl6V4

Table 2 Material properties

Name	Density [kg/m^3]	Spec. Heat Cap. [J/kgK]	Melting Temperature [K]	Specifc Heat Melting [J/kg]	Emission Coefficient [-]
A316	8030	611.5	1650	274000	0.59
AA6060	2700	1071.4	900	389000	0.155
SSiC	3100	600	1800	*200000*	0.8
Cork	480	2100	2300	*200000*	0.8
FR4	1850	600	370	*100000*	0.4
TiAl6V4	4420	746.4	1900	400000	0.392

3.3 Risk assessment results

The used input parameters lead to the following casualty probability:

Table 3 Casualty probability for break-up and baseline scenario

Configuration	Min.	Avg.	Max.
Break-up (complete)	4.2251E-05	1.2150E-04	1.3232E-04
Break-up (partial)	5.0685E-05	4.5897E-05	3.4778E-05
No break-up	8.3538E-06	1.0854E-05	1.1509E-05

In the case of uncontrolled break-up of QARMAN, multiple objects are estimated to impact the ground. From all listed objects (15 objects with 3.7 kg), 11 objects mainly out of titanium and ceramic with a total mass of 2.5 kg are projected for impact. In case of detachment of the AeroSDS panels, the main body and the four panels will reach ground. The distribution for probability is shown in Figure 7 and the trajectories for all impacting objects are given in Figure 8.

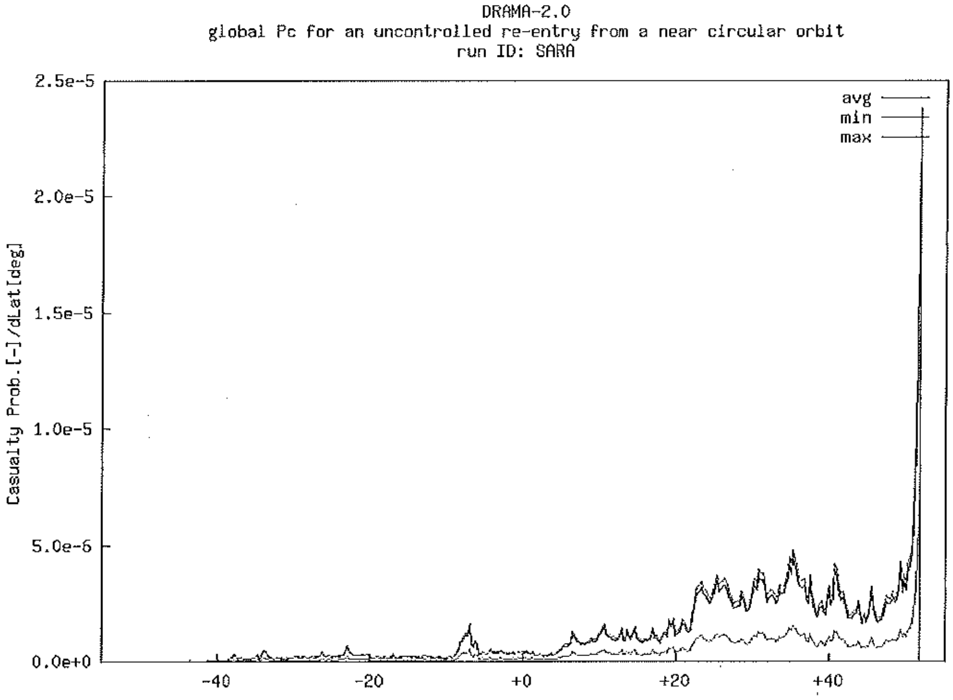

Figure 7 Casualty probability for uncontrolled re-entry with complete break-up

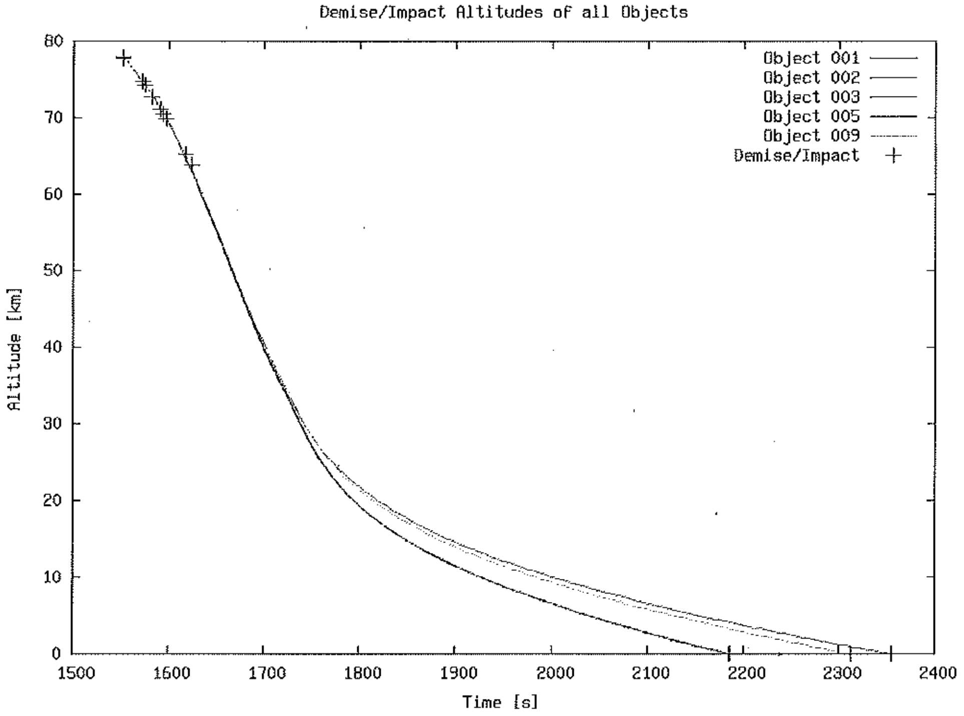

Figure 8 Trajectories for ground impacting objects for complete break-up case

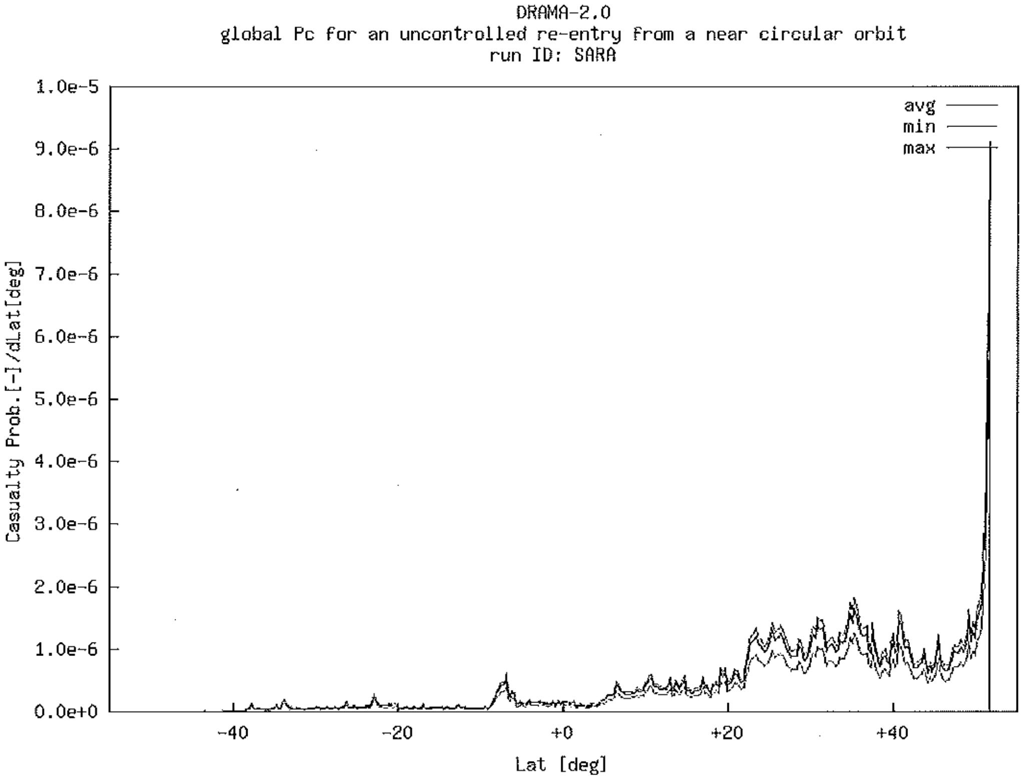

Figure 9 Casualty probability for uncontrolled re-entry with partial break-up

Figure 10 shows the casualty probability for the baseline scenario where QARMAN is impacting the ground with almost complete launch mass. Note that the ablative TPS will lose mass during re-entry resulting in a decreased impact mass.

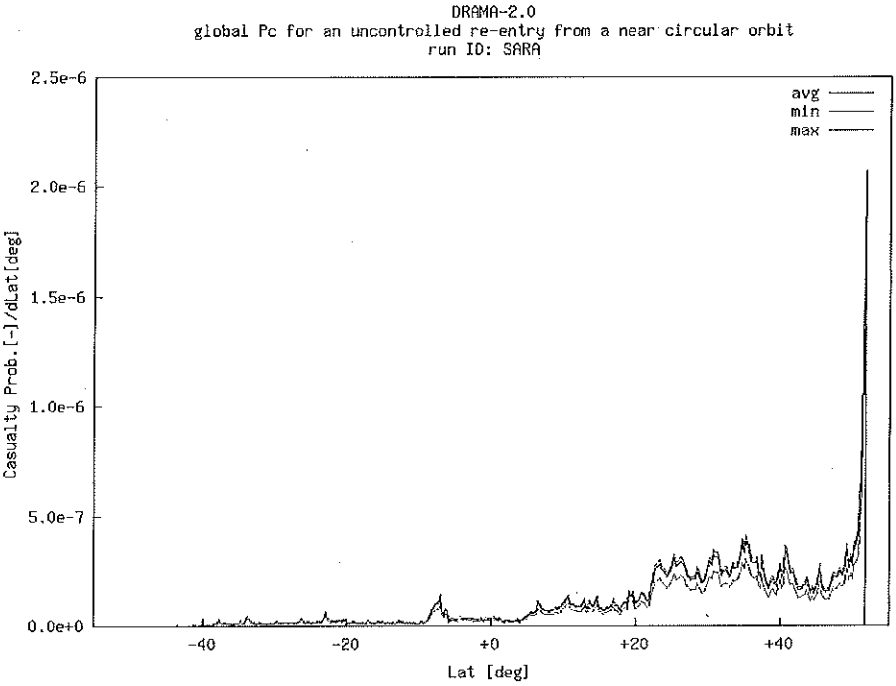

Figure 10 Casualty probability for uncontrolled re-entry with no break-up

The impact energies for the cases with ground impact have been summarized in the following Table 4 derived from the impact velocity and the initial mass of the part to have a conservative estimate.

Table 4 Impact energy for both scenarios

Case	Part	Amount [-]	Impact energy [J]
Break-up (complete)	Side TPS	8	90
	AeroSDS Panels	4	73.75
	Back TPS	1	90.62
	Front TPS	1	181.20
	SU OBC	1	85.89
Break-up (partial)	AeroSDS Panels	4	73.75
	QARMAN body	1	5241.136
No break-up	QARMAN	1	5370.749

Note that all cases in the preliminary analysis for the baseline with no break-up and partial break-up result in a casualty probability which is lower than the threshold of 1 in 10000, as specified in IPOL(2014)2. However in case of the unlikely complete break-up, a maximum risk of 1 in 7553 for causalities is observed. It is VKI's opinion that the break-up of QARMAN is unlikely (assumed to be less than 25% of probability) and in case of break-up, the panels will only detach with the QARMAN main body intact. However due to the complex system, interconnection between the aerothermodynamics and flight mechanics (uncertain flight conditions), a precise estimation of likelihood or probability can be not given.

In case of non-deployment of the AeroSDS due to either software or hardware failure, the estimated lifetime in orbit will be approximately 0.38 years (138 days) assuming a mass of 5 kg and ram-direction flight resulting in a drag coefficient of 3.3 and a deployment at 400km of altitude.

3.4 Passivation

With regard to passivation, the batteries will be still charged at end of life due to the mission concept of retrieving all data after re-entry and transmitting it to mission control before ground impact which requires a working CubeSat with at least partially charged batteries. The reaction wheel, on the other hand, will be passivated after phase 1 (differential drag phase) since it is not required in phase 2, phase 3 and phase 4. The passivation will be performed by gradually slowing down the reaction wheel and compensating the induced torque with magnetorquers and aerodynamic moments provided by the deployed AeroSDS. No other energy storing systems are incorporated into QARMAN.

3.5 Launcher related risks

The QB50 launch provider has foreseen following measures to comply with the Space Debris Mitigation Rules:

- Potential of break-ups during operational phases is minimized;
- Collision risk will be calculated and minimized (for the collision risk among QB-50 CubeSats collision avoidance will be performed by VKI)
- Risk of post-mission break-ups of the third stage resulting from stored energy will be minimized either by passivation of the third stage or controlled re-entry of the third stage.

4. Verification Control Matrix

Req. ID (ISO24113:2011)	Requirement	Compliance	Rationale
6.1.1.1	Spacecraft and launch vehicle orbital stages shall be designed not to release space debris into Earth orbit during normal operations	Compliant	Compliant by design
6.1.1.2	Space debris released into Earth orbit as part of normal operations, other than those covered by 6.1.2, shall remain outside the GEO protected region and limit their presence in the LEO protected region to a maximum of 25 years after their release	Not applicable	No debris released as part of normal operations
6.1.2.1	Pyrotechnic devices shall be designed to avoid the release into Earth orbit of products larger than 1 mm in their largest dimension.	Not applicable	No pyrotechnic devices on board
6.1.2.2	Solid rocket motors shall be designed and operated to avoid releasing solid combustion products into the GEO protected region	Not applicable	No solid rocket motors on QARMAN
6.1.2.3	In the design and operation of solid rocket motors, methods to avoid the release of solid combustion products that might contaminate the LEO protected region shall be considered.	Not applicable	Same as above
6.2.1	In Earth orbit, intentional break-up of a spacecraft or launch vehicle orbital stage shall be avoided.	Compliant	No intentional breakup foreseen
6.2.2.1	The probability of accidental break-up of a spacecraft or launch vehicle orbital stage shall be no greater than 10^{-3}, until its end of life	Compliant	See answer to RID 71
6.2.2.2	The determination of accidental break-up probability shall quantitatively consider all known failure modes for the release of	Compliant	See answer to RID 71

	stored energy, excluding those from external sources such as impacts with space debris and meteoroids.		
6.2.2.3	During the disposal phase, a spacecraft or launch vehicle orbital stage shall permanently deplete or make safe all remaining on-board sources of stored energy in a controlled sequence.	Compliant	No disposal phase foreseen, since QARMAN is supposed to operate up to ground impact
6.3.1.1	The probability of successful disposal of a spacecraft or launch vehicle orbital stage shall be at least 0,9 at the time disposal is executed.	Compliant	No disposal phase foreseen, since QARMAN is supposed to operate up to ground impact
6.3.1.2	The probability of successful disposal, as discussed in Annex A, shall be evaluated as conditional probability weighted on the mission success	Compliant	No disposal phase foreseen, since QARMAN is supposed to operate up to ground impact
6.3.1.3	The start and end of the disposal phase, as illustrated in Annex B, shall be chosen so that all disposal actions are completed within a period of time that ensures compliance with 6.3.1.1.	Compliant	No disposal phase foreseen, since QARMAN is supposed to operate up to ground impact
6.3.2.1	A spacecraft or launch vehicle orbital stage operating in the GEO protected region, with either a permanent or periodic presence, shall be maneuvered in a controlled manner during the disposal phase to an orbit that lies entirely outside the GEO protected region.	Not Applicable	Not Applicable
6.3.22	A spacecraft operating within the GEO protected region shall, after completion of its GEO disposal manoeuvres, have an orbital state that satisfies at least one of the following two conditions: a) the orbit has an initial eccentricity less than	Not Applicable	Not applicable

	0,003, and a minimum perigee altitude, ΔH (in km), above the geostationary altitude in accordance with $\Delta H = 235 + 1000 \times C_R \times A/m$ b) the orbit has a perigee altitude sufficiently above the geostationary altitude that long-term perturbation forces do not cause the spacecraft to enter the GEO protected region within 100 years.		
6.3.3.1	A spacecraft or launch vehicle orbital stage operating in the LEO protected region, with either a permanent or periodic presence, shall limit its post-mission presence in the LEO protected region to a maximum of 25 years from the end of mission.	Compliant	No disposal phase foreseen, since QARMAN is supposed to operate up to ground impact. In case of accidental failure, QARMAN will reentry in any case within 25 years as shown in the lifetime analysis
6.3.3.2	After the end of mission, the removal of a spacecraft or launch vehicle orbital stage from the LEO protected region shall be accomplished by one of the following means (in order of preference): a) retrieving it and performing a controlled re-entry to recover it safely on the Earth, or b) manoeuvring it in a controlled manner into a targeted re-entry with a well-defined impact footprint on the surface	Compliant	No disposal phase foreseen, since QARMAN is supposed to operate up to ground impact. In case of accidental failure, QARMAN will reentry in any case within 25 years as shown in the lifetime analysis

	of the Earth to limit the possibility of human casualty, or c) manoeuvring it in a controlled manner to an orbit with a shorter orbital lifetime that is compliant with 6.3.3.1, or d) augmenting its orbital decay by deploying a device so that the remaining orbital lifetime is compliant with 6.3.3.1, or e) allowing its orbit to decay naturally so that the remaining orbital lifetime is compliant with 6.3.3.1, or f) manoeuvring it in a controlled manner to an orbit with a perigee altitude sufficiently above the LEO protected region that long-term perturbation forces do not cause it to re-enter the LEO protected region within 100 years.		
6.3.4.1	For the re-entry of a spacecraft or launch vehicle orbital stage (or any part thereof), the maximum acceptable casualty risk shall be set in accordance with norms issued by approving agents.	Compliant	Verified by analysis
6.3.4.2	The re-entry of a spacecraft or launch vehicle orbital stage (or any part thereof) shall comply with the maximum acceptable casualty risk, according to 6.3.4.1.	Compliant	Verified by analysis

5. Battery Brake-Up analysis

QARMAN battery brake-up risks shall be assessed according to ESA Space Debris requirement 6.2.2.1. and the following chapter covers the analysis
The Clyde Space Flex Electrical Power System (EPS) includes battery protection circuitry, as well as latch-up protection on all switched outputs. The regulated bus protection is triggered over 2.5 A. Moreover the secondary battery protection circuit on OBC switches off the power if the current flow reaches over 3A. This protection circuitry would have to fail concurrently with the battery to cause explosive energy release. Table 1 shows the probability of spacecraft breakup due to catastrophic battery failure. It is based on a three month mission lifetime, and is based on typical failure rates of the components of the battery protection circuitry. The M failure rate level is specified as 1% per 1000 hours of testing. The three-month nominal mission is approximately 2000 hours. This means that M failure rate levels for components (the lowest component failure rating) of the battery protection or latch-up protection circuitry means there is a 2% chance of failure in three months.

Table 5 Probability of Spacecraft Breakup due to sudden battery energy release. Probability over a 3 month timespan

Probability of latch-up protection circuitry failure (prevents >2.5 A draw)	2e-2
Probability of battery protection circuitry failure (prevents >3 A draw)	2e-2
Probability of battery explosion given unprotected overcurrent draw	1
Probability of spacecraft break-up due to battery failure	4e-4

The only circumstance which could cause satellite breakup has a probability under the 1e-3 limit; thus the mission is compliant with requirement ESA Space Debris requirement 6.2.2.1. In reality, the likelihood of a battery explosion given unprotected overcurrent conditions is likely less than unity, but without a test we cannot assume differently. The analysis is supported by other sources of failure rate data (i.e. https://www.electrochem.org/dl/interface/sum/sum12/sum12_p037_044.pdf gives a Li-Ion battery + protection circuitry failure rate of less than 1e-7).

In the highly unlikely event of a battery explosion, the consequences would not lead to satellite breakup since the explosion products are contained within three layers of protection (ie. the survival unit and ceramic TPS).

6. Conclusion

QARMAN fulfills the requirements on the space debris given in [**ii**] if applicable. The casualty risk calculation was performed with the DRAMA software suit and a probability less than the required 1 in 10,000 was obtained.

References

[i] R. Reinhard. Requirements document for QB50. Technical report, Brussels, Belgium.
[ii] ~~Space debris mitigation for Agency projects. ESA-ADMIN-IPOL(2014)2~~
[iii] QARMAN: QB50 Qubesat for Aerothermodynamic Research and Measurements on AblatioN. Technical, implementation, management and financial proposal. 28/08/2013.
[iv] ESSB-HB-U-002 ESA Space Debris Mitigation Compliance Verification Guidelines, 19/02/2015.