Re-entry Platform for In-flight Demonstration and In-situ Measurement

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Abstract

The von Karman Institute for fluid dynamics is aiming to develop and launch a re-entry vehicle by June 2015. Based on the CubeSat standard, with a highly constraining form factor (34x10x10cm), the vehicle will be developed in the frame of the PhD thesis and will represents a low-cost approach for the study of ablation and radiation in the harsh aerothermodynamics environment.

Keywords: re-entry, CubeSat, ablation, radiation, de-orbitation

1. Introduction

In the frame of the QB50 project led by the von Karman Institute for Fluid Dynamics (VKI) the paper exposes the preliminary results of the PhD thesis for the development of a re-entry CubeSat. More detailed data could be found in Bailet et al. (2011). The scientific objective of the QB50 project is to study the temporal and spatial variations of a number of key constituents and parameters in the lower thermosphere (50-320 km) with an international network of 50 double CubeSats (Fig. 1), miniaturized satellites weighing 2 kg in a 20x10x10 cm3 volume. The 50 CubeSats in a circular orbit will be separated by a few hundred kilometers and will carry identical sensors that will perform in-situ, long duration (~3 months) and multi- point measurements. QB50 will also study the re-entry process by measuring a number of key parameters during the re-entry process with the vehicle presented in this paper.

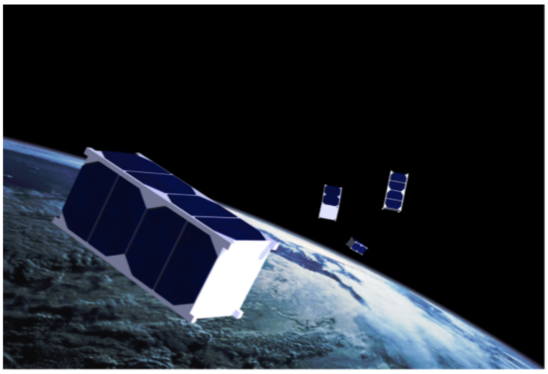

Figure 1: Artistic impression of few double-unit CubeSats of the QB50 constellation

2. Re-entry CubeSat concept

A low cost nano-size re-entry spacecraft for in-situ measurements and in-orbit demonstration will permit huge opportunities for independent research institutions and industries to test materials or subsystems in real flight conditions as it is not fully duplicable on ground. A very attractive part of such a mission is to provide an affordable low cost platform to validate ground testing and numerical simulations that are designed to understand the scientific background of the atmospheric re-entry of spacecraft.

The main difference between the proposed re-entry CubeSat platform and the 49 other QB50 CubeSats of the program is the need of an extra unit for the thermal protection system (TPS) to deal with the re-entry constraints. Such CubeSat standard, a 3-Unit (3U) CubeSat, imposes a platform that does not exceed 34x10x10 cm in shape and 3 kg in mass. The challenging part of the re-entry is located below 120 km of altitude. The first step of the study has focused on a target minimum altitude expected between 50 and 70 km. A low altitude target is a challenge, because for every other re-entry vehicle, the payload is designed first and then the external shape of the spacecraft is defined such that it covers the integrity of the payload and permits a defined mission scenario to be executed. A major mission-constraint is to enforce the destruction of the vehicle before it reaches the ground thus avoiding any problem of collision with ground assets.

3. Feasibility analysis and conceptual design

After a shape definition by means of multi-criteria optimization (Bailet et al., 2011), it clearly appeared that the thermal protection system is one of the most crucial subsystems. Two different parts can be distinguished, the heat shield (first third of the vehicle) and the side panels. The heat shield part has been shown to be realistically feasible, through plasmatron tests and thermal response simulations. The Cork P50 has been chosen as TPS for its high thermal resistance capability and its affordability and availability. It appears in the second part that the thermal limitations would come from the side panels. In fact, the side panels in the standard concept (1.5 mm thick of aluminum) are not suitable at all to reach the most interesting part of the trajectory and should be two times and half the original size for an increased thermal protection of the sub-systems. This option is not desirable at all and a composite panel with the adjunction of a Nextel insulation layer has been selected as appropriate for the mass/volume budget and the thermal viability of the vehicle during the re-entry.

The proposed spacecraft design permits to carry out the experiment in-flight as expected. To provide these data as exploitable, the necessity to recover them without loss and with a suitable data rate according to the experiment sampling is needed. It has been shown that the most feasible system is to transmit the data up to the LEO/MEO orbit and then transmit it down to the ground stations. This methodology permits to avoid the re-entry black out and so have scientific return during the most interesting part of the trajectory hardly accessible otherwise. The choice of the scientific experiments in accordance with the available mass/volume capacity will permit in future studies to size the communication system in more details as applying new constrains on the power budget.

An adequate power budget is needed to avoid any incertitude in the orbital dynamic calculations. Actually, the re-entry will be extremely demanding for the power supply system. In only 10 minutes all flight experiments and subsystems of the vehicle will work in full regime and the antenna will need lots of energy to transmit the signal with an efficient gain. The next table presents the power budget with margins required to perform the experiments and transmit the data. A security margin equal to two is applied to the payload and the amplifier power budget to ensure that the designed equipment will be within this power consumption. The Communication system uses the HISPICO patch antenna (5 W) and the Iridium transceiver (¡1 W) to be the interface between the data acquisition system and the satellite relay communication system. A synthesis of the power budget is presented hereafter in Table 1.

Table 1: Power budget of the nano-size re-entry vehicle

Subsystem	*Power needed including margins W*
Functional unit (Avionic)	2
Telecommunication system	2
Payload + amplifier	6
Total	10

The available batteries are able to bring 10 Whr for each with a maximum of 30 Whr with three stackable batteries. The lifetime of the vehicle between 120 km (re-entry interface) and 50 km (targeted altitude) is 600 seconds but the power system have to be conceive in the optic to provide energy as soon as the solar panels stop their jobs. In the worst case, the Vehicle will have to spend a half of orbit before the re-entry (20 000 km at an altitude superior at 120 km) in the shadow of the earth and so the batteries should sustain the power supplement of the vehicle during this time estimate at 45 minutes. In reality, at an altitude above 120 km and so during this time, all subsystems will not be used. Actually, only the subsystems of the functional unit will consume some power and then, the real power budget will be lower. The most critical case (55 minutes of flight on the batteries) will consume 10 W of power. Considering this case, the power supply should have a capacity of at least 9 Whr. A single battery is at the limit of the needed power.

By adding a security margin, two batteries will be sufficient to perform the minimal experiments required and furnish 12.2 W of supplementary power for more demanding experiments. In the aim to add supplementary payloads a third battery (maximum a stackable batteries) could be needed to reach the limit of 33.3 W in total.

4. Conclusion

The feasibility study has shown the multi-disciplinary complexity of a nano-scale re-entry CubeSat and the necessity for each sub-system to be considered in a mass/volume optimization point of view, for the purpose of respecting the 3-unit CubeSat standard (3kg total weight limit and 3000cm3). Although the methodologies and results presented in this study have their limitations in both physical modeling and accuracy, the first approach permits to draw up the mass budget of the mission (Table 2).

All the work performed has been compiled to give the mass and power budgets for the vehicle and so demonstrate the interesting and feasibility of the proposed platform with a payload mass of minimum 0.612 kg. The mass available, associated to the payload mass, and the extra margins permits to be confident on the expected scientific return. Future studies within the PhD will permit to select the payloads according to the scientific objectives (ablation and radiation) through aerothermodynamics and line of sight simulations. The work presented in this paper has identified and treated the different critical challenges of the re-entry mission including the system view on the vehicle.

From the feasibility analysis to the final conceptual design every aspect of the mission have been covered and analyzed. The result of the study is promising for both system view and potential scientific return. For illustration purpose, Fig. 2 shows the proposed configuration for the re-entry CubeSat with external and internal composition.

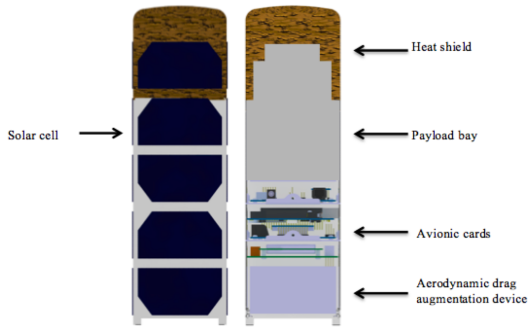

Figure 2: Re-entry CubeSat configuration external view (left) and internal view (right)

The nano-scale reentry vehicle remains an extraordinary opportunity for science and engineering in terms of in-situ experiment and in-flight demonstration capabilities and should be consider as the future low cost platform for in-flight experimentations.

Table 2: Mass budget of the nano-size re-entry vehicle

Subsystem	*Mass* *kg*	*Margins* *%*	*Mass including margins* *kg*
Heat shield	0.317	20	0.380
Functional unit (Avionic, Structure, Side panels, (Telecommunication system	1008 +0.036 (nose support) +0.173(Nextel blanket) +0.03 (transceiver)	0 30 10 10	1.248
Deorbiting system	0.400	30	520
Stability system	0.200	20	240
Total	1.937	-	2.388
		Payload	0.612-1.063

Acknowledgments

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References

[1] Bailet et al., Feasability Analysis and Preliminary Design of an Atmospheric Re-Entry Cubesat Demonstrator, 7th symposium on aerothermodynamics, ESA conference, Bruges, May 2011.